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CHEMICAL THEORY OF GUNPOWDER.

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According to Bellani, the English army used cannon at the battle of Crecy in the year 1346. The correctness of this report has been doubted, since English and French writers in their description of the battle do not mention the use of cannon. However this may be, it is certain that from the middle of the 14th century the application of powder to the purposes of the art of war became more and more general, until towards the close of the Middle Ages heavy ordnance was used by all European armies. The effect of this new application of gunpowder upon the civilization of our race is usually considered to have been of the same importance as the invention of the art of printing or the discovery of America. And, although 536 years have passed away since the battle of Crecy was fought, we have to this day no satisfactory account of the chemical reactions which occur during the combustion of gunpowder, no theory to enable us to determine the quantitative relations of the products of combustion *à priori* from the composition of the powder. The attempts which have been made from time to time by eminent men to supply solutions of the problems indicated, have been, as is well known, unsuccessful.

In the following pages I propose to describe a theory which explains in a satisfactory manner the chemical reactions which occur during and after the explosion, not only of a powder of normal composition, but, generally, of a mixture of x molecules of saltpetre, y atoms of carbon, and z atoms of sulphur.

Until about the year 1856 the metamorphosis of gunpowder was represented in chemical text-books to take place according to the equation

$$2KNO_3 + 3C + S = K_2S + N_2 + 3CO_2.$$

This equation is obviously not correct, because besides sulphide, also sulphate and carbonate of potassium are formed.

After the publication of Bunsen's and Schischkoff's * classical investigation in 1857, the incorrectness of the equation was generally recognized, and the view expressed that the explosion of gunpowder could not be represented by a chemical equation on account of its complex nature. Passing by for the present the papers published between the years 1858 and 1874, I propose to take at once into consideration the most recent and important investigation by Noble and Abel; † I do so because we receive from the pages of their papers a very complete account of our present knowledge of the combustion of gunpowder.

Five different descriptions of powder were used in their experiments:

1. Pebble powder (P.); 2. Rifle large grain (R. L. G.); 3. Rifle fine grain (R. F. G.); 4. Fine grain (F. G.); and 5. Spanish pebble powder.

The first four descriptions were manufactured at Waltham Abbey.

It will be convenient for the purposes of reference to give in the following table the composition of these powders.

TABLE I.—*Showing the Composition of the Powders used by Noble and Abel.*

Constituents of powder.	Powders from Waltham Abbey.				Spanish.
	P.	R. L. G.	R. F. G.	F. G.	
Saltpetre	74.67	74.95	75.04	73.55	75.30
Potassic sulphate	0.09	0.15	0.14	0.36	0.27
Potassic chloride	.....	.....	.....	.....	0.02
Sulphur	10.07	10.27	9.93	10.02	12.42
Charcoal: Carbon	12.12	10.86	10.67	11.36	8.65
Charcoal: Hydrogen	0.42	0.42	0.52	0.49	0.38
Charcoal: Oxygen	1.45	1.99	2.66	2.57	1.68
Charcoal: Ash	0.23	0.25	0.24	0.17	0.63
Charcoal: total	14.22	13.52	14.09	14.59	11.34
Water	0.95	1.11	0.80	1.48	0.65

* Pogg. Ann., Bd. cii, p. 321, and Proc. Nav. Inst., Vol. V, p. 538.

† Phil. Trans., Vol. 165 (1875), p. 49, Vol. 171 (1880), p. 203.

Noble and Abel burnt from 100 to 700 grams of powder in hermetically closed steel cylinders.* The analyses of the products of combustion obtained in 31 experiments have been published, and of these it will be desirable to reproduce a few representative cases in Table II.

TABLE II.—*Containing the Results of Nine Experiments Calculated for 1 gram of Powder.*

Products of combustion.	F. G.			R. L. G.			P.		
K_2CO_3	0.2429	.2615	.3255	.3007	.3017	.3635	.2879	.3098	.3680
$K_2S_2O_3$	.1851	.1666	.0780	.1166	.0740	.0369	.1845	.0338	.0761
K_2SO_4	.1288	.1268	.1204	.1171	.1395	.0625	.0733	.0658	.0523
K_2S	.0000	.0196	.0252	.0230	.0337	.0565	.0128	.1055	.0220
KCNS	.0009	.0004	.0004	.0000	.0003	.0015	.0022	.0013	.0033
KNO_3	.0010	.0005	.0005	.0032	.0002	.0000	.0014	.0011	.0025
$(NH_4)_4H_2(CO_3)_3$	.0186	.0002	.0005	.0003	.0002	.0006	.0003	.0004	.0007
S	.0026	.0068	.0356	.0041	.0262	.0480	.0111	.0340	.0484
H_2S	.0090	.0080	.0088	.0041	.0127	.0067	.0129	.0084	.0086
CO	.0316	.0339	.0343	.0303	.0390	.0472	.0419	.0473	.0362
CO_2	.2689	.2678	.2650	.2597	.2610	.2677	.2630	.2770	.2710
CH_4	.0003	.0000	.0005	.0006	.0000	.0007	.0007	.0012	.0013
H	.0006	.0008	.0007	.0005	.0007	.0005	.0005	.0005	.0005
N	.1096	.1071	.1096	.1201	.1108	.1077	.1075	.1139	.1090
No. of experiment.	XL.	XIX.	LXXV.	I.	IV.	XXXIX.	XXXVIII.	XIV.	LXXVII.

From this table it is clear that not only powders of different description, but also mixtures of the same nature, will yield during combustion the products in variable quantities. The salts of potassium, especially the hyposulphite and sulphide, vary considerably in different experiments.

Noble and Abel draw the following conclusions from the results of their investigations:

1. "The variations in the composition of the products of explosion furnished in close chambers by one and the same powder, under different conditions as regards pressure, and by two powders of similar composition under the same conditions as regards pressure, are so considerable, that no value whatever can be attached to any attempt to give a general chemical expression to the metamorphosis of a gunpowder of normal composition (p. 137).

"Any attempt to express, even in a comparatively complicated chemical equation, the nature of the metamorphosis which a gunpowder of average composition may be considered to undergo when

* Phil. Trans., Vol. 165 (1875), p. 61.

exploded in a confined space, would therefore only be calculated to convey an erroneous impression as to the simplicity or the definite nature of the chemical results and their uniformity under different conditions, while it would, in reality, possess no important bearing upon an elucidation of the theory of explosion of gunpowder (p. 85).

2. "The proportions in which the several constituents of solid powder residue are formed, are quite as much affected by slight accidental variations in the conditions which attend the explosion of one and the same powder in different experiments, as by decided differences in the composition as well as in the size of grain of different powders (p. 137).

3. "Very small grain powder, such as F. G. and R. F. G., furnish decidedly smaller proportions of gaseous products than a large grain powder (R. L. G.), while the latter again furnishes somewhat smaller proportions than a still larger powder (pebble), though the difference between the gaseous products of these two powders is comparatively inconsiderable.

4. "In all but very exceptional results, the solid residue furnished by the explosion of gunpowder contains as important constituents, potassium carbonate, sulphate, hyposulphite and sulphide, the proportion of carbonate being very much higher, and that of sulphate very much lower than stated by recent investigators."

The view of Noble and Abel may be briefly stated as follows:

One and the same description of powder, exploded several times in succession, will yield the products of combustion, in the different experiments, in variable proportions; hence, the metamorphosis of gunpowder cannot be represented by a chemical equation.

One might suppose that, perhaps, the pressure developed during explosion had an influence on the quantities of the products of combustion. From a comparison of the analytical results and the corresponding pressures, published by Noble and Abel, this, however, appears not to be the case.* (See p. 85 of their first memoir.)

According to Noble and Abel, the chemical metamorphosis of gunpowder during explosion is a very complicated process, which cannot be explained with the data at their disposal. Berthelot† arrived at a different conclusion.

* An increase of pressure appears to diminish the amount of carbonic oxide. But this is not always the case, and when it does occur, it is not sufficient to explain the variations in the other products of combustion.

† Comptes Rendus, tom. lxxxii, p. 487.

The composition of the powders of Waltham Abbey can, according to him, be represented by the symbols

$$2KNO_3 + 3C + S$$

which require for 100 parts of powder:

Saltpetre	74.8
Carbon	13.3
Sulphur	11.8

The analysis gave:

Saltpetre	73.55 to 75.04
Carbon	10.67 " 12.12
Sulphur	9.93 " 10.27

The combined weights of potassic sulphocyanate, ammonic carbonate, hydrogen, marsh gas, and sulphuretted hydrogen amount, according to Table II, to about 1.5 per cent. They evidently originate from secondary reactions, and may, accordingly, be neglected in the following considerations.

A theory of the explosion of gunpowder ought to explain the formation of potassic carbonate, potassic sulphate, potassic sulphide, carbonic acid and carbonic oxide. Potassic hyposulphite is not a primary product, but is formed during the analysis of the powder residue.

If we select two from several experiments published by Noble and Abel, viz. one in which the maximum amount of potassic carbonate and the minimum of sulphate were produced, and another which yielded the largest quantity of potassic sulphate and the smallest of carbonate, then, according to M. Berthelot, the explosion which produced the results of the first case may be represented by three equations—

$\frac{1}{3}$ of the powder was transformed according to equation

$$2KNO_3 + 3C + S = K_2S + 3CO_2 + N_2, \quad . \quad . \quad . \quad I.$$

$\frac{1}{2}$ according to

$$2KNO_3 + 3C + S = K_2CO_3 + CO_2 + CO + N_2 + S, \quad . \quad II.$$

$\frac{1}{6}$ according to

$$2KNO_3 + 3C + S = K_2CO_3 + 1.5CO_2 + 0.5C + S + N_2 \quad . \quad III.$$

and in the second case, with a maximum of potassic sulphate,

$\frac{1}{8}$ of the powder was transformed according to equation I,
about $\frac{1}{2}$ according to III,
$\frac{1}{8}$ according to

$$2KNO_3+3C+S=KS_2O_4+2CO+C+N_2, \quad . \quad . \quad IV.$$

and $\frac{1}{12}$ according to

$$2KNO_3+3C+S=K_2SO_4+CO_2+C_2+N_2 \quad . \quad . \quad V.$$

Between the limits marked by these two cases are contained all the experimental results of Noble and Abel. If, therefore, we assume that in a given experiment one portion of the powder used burnt according to the equations of the first, and the rest according to those of the second case, the calculated results will agree with the observations. And if the proportions of powder, which are transformed according to the one or other system of equations, be changed from experiment to experiment, the quantities of the products of combustion obtained in each experiment can be calculated in a satisfactory manner.

The assumption that during explosion one portion of the powder is transformed according to one, and another portion according to another, equation or system of equations is justified in the opinion of M. Berthelot by the further assumption, that the local conditions in a mass of burning powder are not the same in all parts, and that the cooling is too rapid to allow the products to assume a state of chemical equilibrium.

If the products were left in contact at a high temperature for a longer time, they would react upon each other, and the final result would be the same as that represented by equation V, to which corresponds the greatest evolution of heat.

This theory of M. Berthelot is very ingenious, but does not agree with experience. Considerable amounts of carbon ought to be left free at the end of each explosion. In twenty-eight experiments of Noble and Abel no free carbon was left, and only in three cases small insignificant quantities had escaped combustion. The equations III, IV and V cannot be applied to the combustion of the powders of Waltham Abbey. But even if the theory were correct, it would possess no practical value, because the quantities of the powder which would burn according to each of the two systems of equations could not be known *à priori*, but would have to be found by experiment.

Berthelot invented his theory in order to explain the remarkable result of Noble and Abel's experiments, that the same description of

powder, or powders of similar composition, yield the products of explosion, in different experiments, in variable proportions.

We will now proceed to show that this result can be explained, without hypothesis or theory, in a very simple manner.

For this purpose it is desirable to express the analytical results of Noble and Abel in a manner different from the one adopted by these investigators.* If we divide the numbers of Table II by the corresponding molecular weights, we obtain another table expressing the number of molecules of the products obtained in the different experiments by the explosion of 1 gram of powder. For experiment XIX we have:

K_2CO_3	. . . .	0.2615 gram	or 0.00189 mol.
K_2SO_4	. . . .	0.1268 "	0.00072 "
$K_2S_2O_3$	. . . .	0.1666 "	0.00087 "
K_2S_2	. . . . .	0.0252 "	0.00017 "
S	. . . . .	0.0012 "	0.00004 atom.
CO_2	. . . . .	0.2678 "	0.00608 mol.
CO	. . . . .	0.0339 "	0.00121 "
N	. . . . .	0.1071 "	0.00765 atom.
H_2S	. . . . .	0.0080 "	0.00023 mol.
CH_4	. . . . .	0.0000 "	0.00000 "
H	. . . . .	0.0008 "	0.00080 atom.
KCNS	. . . .	0.0004 "	
KNO_3	. . . .	0.0005 "	
$Am_4H_2(CO_3)_3$	. .	0.0002 "	

Potassic carbonate, sulphate, sulphide, and hyposulphite, carbonic acid and carbonic oxide, nitrogen and sulphuretted hydrogen together form more than 98 per cent. of the exploded powder; accordingly, hydrogen, marsh gas, ammonic carbonate, potassic sulphocyanate and undecomposed saltpetre may, as non-essential products, be left out of consideration.

Potassic carbonate, sulphate, hyposulphite and sulphide contain very nearly the entire amount of potassium of the exploded powder. If, therefore, we add the number of molecules of these bodies and multiply the sum by two, we obtain the number of molecules of saltpetre in 1 gram of powder. In order to compare the results of experiments made with the same or with different descriptions of gunpowder it is desirable to calculate these results, not, as is usually done,

*Noble and Abel discuss only the percentage quantities of the products of explosion.

for the same quantity of powder, but for such quantities as contain equal amounts of saltpetre or oxygen.

The products of Experiment XIX contain 0.00730 atom of potassium and are derived from a weight of powder containing 0.0073 mol. of saltpetre. The same products contain 0.00189 mol. of K_2CO_3, hence:

$$0.00730 : 0.00189 :: 16 : x \text{ and } x = 4.14.$$

And if the same mode of calculation is extended to the other products, we obtain

$$\begin{aligned} 4.14K_2CO_3 &+ 1.58K_2SO_4 + 13.3CO_2 + 8.38N_2 \\ &+ 1.90K_2S_2O_3 + 2.65CO + 0.08S \\ &+ 0.37K_2S_2 \qquad\qquad + 0.5H_2S \end{aligned}$$

and, from these numbers, the following composition of the F. G. powder,

$$\begin{aligned} 16KNO_3 &+ 20.09C + 6.70S \\ &+ 0.76N + 1.0H \\ &+ 5.69O. \end{aligned}$$

By a similar calculation we obtain:

Experiment LXXV.

$$\left.\begin{aligned} &5.10K_2CO_3 + 13.08CO_2 + 0.56H_2S \\ &1.50K_2SO_4 + 2.65CO \\ &0.89K_2S_2O_3 + 8.5N_2 \\ &0.48K_2S_2 + 1.58S \end{aligned}\right\} = \left\{\begin{aligned} &16KNO_3 + 20.83C \\ &0.5N_2 + 6.38S \\ &4.78O \\ &1.12H \end{aligned}\right.$$

Experiment IV.

$$\left.\begin{aligned} &4.75K_2CO_3 + 12.92CO_2 + 0.80H_2S \\ &1.74K_2SO_4 + 3.03CO \\ &0.85K_2S_2O_3 + 8.6N_2 + 1.11S \\ &0.65K_2S_2 \end{aligned}\right\} = \left\{\begin{aligned} &16KNO_3 + 20.7C \\ &6.65S + 0.6N_2 \\ &+1.60H \\ &+4.63O \end{aligned}\right.$$

Experiment XXXIX.

$$\left.\begin{aligned} &5.70K_2CO_3 + 13.18CO_2 + 0.41H_2S \\ &+0.78K_2SO_4 + 3.64CO \\ &+0.41K_2S_2O_3 + 8.3N_2 + 2.14S \\ &+1.10K_2S_2 \end{aligned}\right\} = \left\{\begin{aligned} &16KNO_3 + 22.52C \\ &+6.35S + 0.3N_2 \\ &+0.82H \\ &+3.45O \end{aligned}\right.$$

Experiment XIV.

$$\left.\begin{aligned} &4.77K_2CO_3 + 13.44CO_2 + 0.51H_2S \\ &+0.79K_2SO_4 + 3.62CO \\ &+0.36K_2SO_3 + 8.67N_2 + 0.21S \\ &+2.04K_2S_2 \end{aligned}\right\} = \left\{\begin{aligned} &16KNO_3 + 21.83C \\ &+6.31S + 0.67N_2 \\ &+1.05H \\ &+1.05O \end{aligned}\right.$$

Experiment LXXVII.

$$\left.\begin{array}{l} 5.95K_2CO_3 + 13.78CO_2 + 0.55H_2S \\ +0.67K_2SO_4 + 2.88CO \\ +0.89K_2S_2O_3 + 8.7N_2 \quad + 2.93S \\ +0.44K_2S_2 \end{array}\right\} = \left\{\begin{array}{l} 16KNO_3 + 22.61C \\ +6.81S + 0.7N_2 \\ +1.10H \\ +5.64O \end{array}\right.$$

These equations represent only the quantitative relations between the constituents of the powders and the products of explosion, and, accordingly, fractions of atoms and molecules are admissible.

Experiments XIX and LXXV were made with F. G., Experiments IV and XXXIX with R. L. G., and Experiments XIV and LXXVII with P. powder of Waltham Abbey.

It will be noticed by comparing two experiments, made with the same description of powder, that the composition of the powder deduced from one of the experiments exhibits considerable differences from the composition derived from the other experiment, and neither of them agrees with the composition found by direct analysis.

The composition of the R. L. G. powder may serve as an example.

According to Experiment IV . . $16KNO_3 + 20.7C + 6.65S + 4.63O$
" " Experiment XXXIX $16KNO_3 + 22.52C + 6.35S + 3.45O$
" " Analysis of powder $16KNO_3 + 19.51C + 6.92S$

The products of combustion of Experiment IV contain 1.2, and of Experiment XXXIX 3 atoms more carbon than the powder used in these experiments, or in other words, the products of explosion in Experiment XXXIX were found to contain 1.67 per cent. more carbon than the R. L. G. powder which was exploded.

The results of other experiments, made by Noble and Abel, differ from each other in a similar manner.

One is forced to conclude either that the methods of analysis adopted by Noble and Abel do not yield exact results, or that the powders exploded did not possess the composition which was attributed to them.

Gunpowder is a mechanical mixture of saltpetre, charcoal and sulphur. It can hardly be expected that such a mixture should, even if the greatest care has been taken by the manufacturer, be perfectly homogeneous. Moreover, the burning of wood into charcoal will not always yield a product containing the same percentage amount of carbon, and as gunpowder is a mixture of 75 parts of saltpetre, 10 of sulphur and 15 of charcoal, it appears *à priori* probable that the same description of powder from the same manufacturer will

not always possess the same percentage composition. The amount of carbon, more particularly, may be expected to vary more or less.

In order to test this conclusion by experiment, I requested the late Mr. Wills to analyse a sample of R. L. G. and one of pebble (P.) powder, both obtained from the Royal Arsenal, Woolwich. His results, placed side by side with those of Noble and Abel, are given below.

	R. L. G.		P.	
	Noble and Abel.	Wills.	Noble and Abel.	Wills.
Saltpetre,	74.95	75.10	74.67	74.26
Sulphur,	10.27	8.96	10.07	9.51
Charcoal—				
Carbon,	10.86	12.09	12.12	11.58
Hydrogen,	0.42	0.54	0.42	0.51
Oxygen,	1.99	2.12	1.45	2.55
Ash,	0.25	0.20	0.23	0.33
Water,	1.11	0.85	0.95	0.76
	99.85	99.86	99.91	99.50

It will be noticed that the amounts of carbon and sulphur found by Wills differ considerably from those found by Noble and Abel. But the best proof that the same description of powder from the same works may vary much in composition has been furnished by Noble and Abel themselves. In their first memoir they assign to R. L. G. powder the above composition; in their second paper "On Fired Gunpowder" they publish the following analysis:

Saltpetre,	74.43
Sulphur,	10.09
Charcoal—	
Carbon,	12.40
Hydrogen,	0.40
Oxygen,	1.27
Ash,	0.21
Water,	1.05
	99.85

The sample used in the first analysis was taken from the top, the one employed in the second from the bottom of the same barrel. Two analyses of powder out of the same barrel, executed by the same chemists, gave amounts of carbon which differ from each other by no

less than 1.54 per cent.! We will now consider the effect of such a difference in the percentage of carbon on the relative quantities of the products of combustion.

If in one experiment 100 grams of powder containing 75 parts of saltpetre, 10 parts of sulphur, and 10.86 parts of carbon, and in a second experiment 100 grams of powder with 74.43 parts of saltpetre, 9 parts of sulphur, and 12.40 parts of carbon had been exploded, then, *cæteris paribus*, in the second experiment more potassic carbonate, more sulphide and less sulphate must have formed than in the first, and the quantitative differences of the same products furnished by the two experiments would be almost as great as the greatest differences actually observed by Noble and Abel for the same description of powder in the whole series of their experiments. We arrive in this manner at a very simple explanation of the experimental results upon which Noble and Abel have based the conclusions mentioned under No. 1 and 2 on p. 525, without the necessity of having recourse to a theory like the one advanced by M. Berthelot, or renouncing all explanation like Noble and Abel.

It follows from Table I that the differences of composition between P., R. L. G., R. F. G., and F. G. powders, one compared with the other, are not greater than the differences between two samples of R. L. G. powder taken out of the same barrel. From this it appears probable that only one mixture of saltpetre, charcoal, and sulphur is prepared at Waltham Abbey, and that from this one mixture the powders P., R. L. G., R. F. G., and F. G., differing only in size of grain and, perhaps, density, are manufactured. We may take then for the composition of the said powders the mean of the numbers of all published analyses. Taking into consideration only the saltpetre, sulphur, and carbon, we obtain—

R. L. G. 1st analysis by Noble and Abel $16KNO_3+19.51C+6.92S$
" 2d " " $16KNO_3+22.40C+6.83S$
F. G. . . . . $16KNO_3+20.80C+6.8S$
P. . . . . $16KNO_3+21.86C+6.79S$

and for the mean $16KNO_3+21.14C+6.83S$.

If also the analyses of the late Mr. Wills are taken into consideration, then the mean composition of the powders of Waltham Abbey would be represented by the symbols

$$16KNO_3+21.18C+6.63S$$

The differences of composition found by analysis for the same description of powder are also of great importance in the calculations of the analytical results of the products of explosion. Noble and Abel determine the potassium in x parts of the solid powder residue, and by means of the number so obtained calculate the weight of the total residue. The amount of potassium in the quantity of powder exploded is known from the analysis of the powder, and as the whole of this potassium must reappear in the solid residue, it is easy to find the total residue if the weight of potassium in x parts of it is known.

The total weight of the powder residue subtracted from the weight of the powder used in the experiment gives as difference the total weight of the gases produced by the explosion.

This mode of calculation requires that the exact composition of the powder used in each experiment should be known. Messrs. Noble and Abel assume the composition of the powders of Waltham Abbey, P., R. F. G., and F. G., to be constant; they also consider in their first memoir that of R. L. G. to be so, but in their second memoir they base the calculations of the later experiments on the second analysis of this description of powder. This assumption is, as a matter of fact, not correct; on the contrary, we may take it as highly probable that in any two experiments made by Noble and Abel with the same class of powder, the powder used in the one experiment was not exactly of the same composition as the powder used in the other. Accordingly the weight of the solid residue as calculated by Noble and Abel will have been found in some experiments too high, in others too low, and as a consequence of this the total weight of the gaseous products cannot have been exact. The correctness of this is proved by the differences between the composition of the powders calculated from the products of combustion, and the composition deduced from direct analysis (see pp. 9, 10). These errors will, however, compensate each other if we take the mean of the analytical results of all the experiments.

Before we proceed to do so it will be desirable to consider another circumstance which is not without influence on the final results of Messrs. Noble and Abel.

They burnt their powders in steel cylinders in quantities from 100 to 750 grams, so that the solid products of combustion after explosion remained from 60 to 120 seconds in contact in a fluid condition at a high temperature. Amongst these products we have not, as is

usually assumed, potassium monosulphide, but disulphide, free sulphur, and potassium carbonate. But a mixture of polysulphides of potassium and potassium carbonate at a bright red or a white heat has a most powerful corroding effect upon metals. It is well known that the celebrated Stahl was of opinion that Moses had dissolved the golden calf of the Israelites by means of a polysulphide of potassium.

"And he took the calf which they had made, and burnt it in the fire, and ground it to powder, and strewed it upon the water, and made the children of Israel drink of it."—(Exod. xxxii. 20.)

Sulphur and ash of wood were known to the Jews, and these, at a high temperature, form liver of sulphur, capable of dissolving gold. The affinity of iron for sulphur is very strong. We may expect that, according to temperature, pressure, time of cooling, and last but not least, the condition of the surface of the cylinder, more or less of the sulphur of the powder would unite with the iron of the apparatus. This would have the same effect upon the products as if a powder with less sulphur had been burnt. If 400 grams of powder of the average composition had been exploded, and 10 grams of its sulphur were to unite with the iron of the apparatus, the potassium carbonate produced would be about 0.20 times greater than the amount obtained by the combustion of the same quantity of powder without this removal of sulphur by the iron of the apparatus.

According to the description given by Noble and Abel of the solid powder residue, considerable quantities of ferrous sulphide were contained in it. Hence the variations in the quantities of the products of combustion of powders exploded in Noble and Abel's apparatus will partly be due to the chemical action of iron and sulphur at high temperatures.

It will be observed by an inspection of the equations on pages 8 and 9, that considerably more oxygen was found in the products of combustion than was contained in the saltpetre of the exploded powder. This excess of oxygen cannot have been derived from the charcoal, or the moisture of the powder, because if it had, equivalent quantities of hydrogen ought to have been liberated. Charcoal contains more hydrogen than is necessary to form water with its oxygen. It is this excess of hydrogen which is set free, or which unites with sulphur, carbon or nitrogen, forming sulphuretted hydrogen, marsh gas, or ammonia.

Hence, the excess of oxygen in the products of explosion must originate from some other source. Noble and Abel, like Linck,

Karolyi and others, adopted the method proposed by Bunsen and Schischkoff for the analysis of the solid powder residue. This method requires that the aqueous solution of the substance should be digested with cupric oxide in order to convert the potassic sulphide into hydrate. The question suggested itself whether or not oxygen from the cupric oxide had formed with potassic sulphide, sulphate or hyposulphite.

27.3 grams pure potassic hydrate were dissolved in water, which previously had been boiled in order to expel the air, and the solution divided into two equal parts. One of these parts was saturated with sulphuretted hydrogen in an atmosphere of hydrogen and then mixed with the other, and the solution of potassic sulphide, so obtained, digested with powder of sulphur in sufficient quantity to produce pentasulphide. The analysis of this liquid gave the following results:

10 cub. centims. diluted with previously boiled water were acidulated with hydric chloride and heated to the boiling point. A precipitate of 1.094 grams of sulphur was obtained. The filtrate evaporated to dryness and ignited, the dry residue moistened with hydric chloride, and then raised to a red heat gave 1.387 grams of potassic chloride, corresponding to 0.726 gram of potassium. On the assumption that 1 atom of sulphur had escaped as sulphuretted hydrogen, the liquid, according to these determinations, contains sulphur and potassium in the proportion of 4.67 atoms of the former to 2 atoms of the latter.

10 cub. centims. of the sulphide mixed with a solution of zinc sulphate, and the filtrate tested with an iodine solution in presence of some starch, required 0.2 cub. centim. of the iodine liquid in order to produce a blue color. 1 cub. centim. of the iodine solution corresponded to 1 cub. centim. of a solution of sodium hyposulphite containing 24.8 grams of the salt in 1 litre.

Therefore, 10 cub. centims. of the polysulphide of potassium contain:

0.0038 gram potassic hyposulphite
2.119 grams potassic polysulphide.

To check these numbers, Mr. Cowper, at my request, dissolved the zinc sulphide in hydric nitrate of 1.5 sp. grav., and determined the zinc and the sulphur in the solution according to the usual methods.

He obtained:

Sulphur	1.285 grams
Zinc	0.556 gram,

or for every atom of zinc 4.69 atoms of sulphur.

180 cub. centims. of the solution of potassic polysulphide were digested in a hermetically closed flask with pure and previously ignited cupric oxide at common temperatures. The liquid assumed a brown color, which still could be observed after two days' digestion. The flask was now placed in water of 35° C., whereupon the color rapidly disappeared. The contents of the flask were now placed upon a filter, the cupric oxide and sulphide well washed, and filtrate and wash water united and kept in a closed bottle.

I. 25 cub. centims. of the liquid so prepared, neutralized with acetic acid, mixed with some starch solution, required 24.6 cub. centims. of iodine solution for the production of the blue color.

25 cub. centims. in another experiment required 24 cub. centims. iodine solution.

25 cub. centims. in a third experiment required 24.2 cub. centims. iodine solution.

The mean of these experiments is 24.26 cub. centims. of iodine solution for 25 cub. centims. of the filtrate, hence 100 cub. centims. of the united filtrate and wash water contain 1.844 grams of potassic hyposulphite.

II. 100 cub. centims. of the same filtrate evaporated with pure hydric sulphate gave 3.653 grams of potassic sulphate, which dissolved in water to a clear and neutral liquid. A similar quantity of hydric sulphate to that which had been used in this experiment, and out of the same bottle, left no residue after evaporation. 3.653 grams of K_2SO_4 contain 1.6375 grams of potassium, 1.844 grams of $K_2S_2O_3$ contain 0.757 gram of potassium; therefore, more than one-third, nearly one-half, of the potassium of the $K_2S_{4.67}$ in the original solution appears after treatment with cupric oxide as potassic hyposulphite.

The presence of potassic hyposulphite is assumed on account of the behavior of the liquid with iodine solution. A direct proof of its presence appeared to be desirable.

Reactions of the Filtrate of the Cupric Oxide.

a. Hydric chloride caused turbidity after some time, probably from sulphur.

b. Barium chloride, a white precipitate, only partly soluble in hydric chloride.

c. Cupric sulphate gave after neutralization with acetic acid a blue precipitate, which turned dark brown at 70–80° C.

A mixture of sodic hyposulphite, potassic acetate and cupric sulphate behaved in a similar manner.

d. Lead acetate and silver nitrate, respectively, gave the same reactions as they do with a solution of sodic hyposulphite.

122 cub. centims. of the strongly alkaline filtrate were neutralized with acetic acid and allowed to evaporate over hydric sulphate under the receiver of an air-pump. After a few days a great number of prismatic crystals were observed. These crystals warmed with alcohol fused into an oily liquid, which recrystallized on cooling and did not dissolve in alcohol.

Alcohol added to the mother-liquor of the crystals produced a crystalline precipitate.

The original crystals and the crystalline precipitate united weighed 2.634 grams.

According to the determination with iodine solution 122 cub. centims. of the filtrate from the cupric oxide contain 2.249 grams anhydrous, or 2.604 grams hydrated salt of the formula $3K_2S_2O_3$, $5H_2O$. The crystals dissolved easily in 3 cub. centims. of water with absorption of heat; from this solution 2.457 grams of salt were reobtained.

0.497 gram of the same, dissolved in water and mixed with a solution of strontium chloride, gave, after two days' standing, a very small precipitate.

0.903 gram of the salt, dissolved in 50 cub. centims. of water, gave on addition of 1 gram of barium chloride a white precipitate, which left, after treatment with boiling water, 0.017 gram of barium sulphate. The filtrates of the barium sulphate yielded a fine crop of barium hyposulphite.

As this salt is, according to my experience, easily obtained in a pure form, the whole of the potassium hyposulphite was converted into the barium compound for the following analytical determinations.

0.882 gram baric hyposulphite boiled with hydric nitrate gave 0.763 gram of baric sulphate; the filtrate of this gave, on addition of barium chloride, another quantity of the same salt, which, after ignition and treatment with hydric chloride, weighed 0.753 gram.

Therefore in 100 parts:

	Experiment.	Theory.	
		BaS_2O_3.	BaS_2O_3, H_2O.
Barium, . . .	50.86	51.70	48.41
Sulphur, . . .	23.60	24.15	22.61

The potassium salt from which the barium hyposulphite had been prepared gave the following reactions:

a. Hydric chloride produced, a few moments after its addition, a slightly yellow turbidity.

b. Cupric sulphate gave a slight turbidity at common temperatures; on boiling, a copious brown precipitate.

c. Lead acetate, a white precipitate, which did not change its color at 100° C.

d. Ferric chloride gave the usual violet color.

e. Silver nitrate, a white precipitate, which turned black at higher temperatures.

According to these experiments there can be no doubt that, by the treatment of a solution of a mixture of potassic penta- and tetra-sulphides with cupric oxide, large quantities of potassic hyposulphite are formed.

The mother-liquor of the potassic hyposulphite, from which this salt had been removed by means of alcohol, was left to evaporate *in vacuo*. The crystalline residue, heated in a platinum crucible, produced an oily liquid, which crystallized on cooling, like potassic acetate, and weighed 2.616 grams.

It was converted by means of hydric sulphate into 2.404 grams of potassic sulphate.

2.616 grams of potassic acetate should give, according to theory, 2.320 grams of potassic sulphate. If we assume that, in the solution obtained by the treatment of potassic polysulphides with cupric oxide, only potassic hyposulphite and potassic hydrate are present, then, according to the numbers given on page 536, 122 cub. centims. of the filtrate from the cupric oxide should have given 2.697 grams potassic acetate, instead of 2.616 as found by experiment.

Hence we may conclude that 100 cub. centims. of the filtrate from the cupric oxide contain:

1.844 grams potassic hyposulphite,
1.263 " " hydrate,

and a very small amount of potassic sulphate.

At my request, Mr. Cowper digested solutions of the other sulphides of potassium with cupric oxide and examined the products for potassium hyposulphite. He found that in a solution of potassic tersulphide (K_2S_3) nearly $\frac{1}{2}$, in one of potassic disulphide about $\frac{1}{3}$, and in one of potassic sulph-hydrate about $\frac{1}{12}$ of the potassium appears after treatment with cupric oxide as hyposulphite. All these experiments lead to the conclusion that the potassic hyposulphite found in solid powder residues by Bunsen and Schischkoff's method had been formed during the analysis of the said residues, and was not one of the original products of explosion. This conclusion is supported by the observation of Pape,* according to which potassic hyposulphite is decomposed at 225° C. into sulphate and pentasulphide of potassium.

At the conclusion of my experiments in July, 1879, I communicated the results to Mr. Abel, and he has since then confirmed my observations.

Noble and Abel say at the end of their second memoir (Phil. Trans., 1880, p. 277), "that although it would seem that in certain cases and under certain exceptional circumstances potassium hyposulphite does exist as a secondary, it exists in no case as a primary product, and should not, therefore, be reckoned among the normal constituents of powder residues."

Wishing to obtain a clear conception of the mode of action of cupric oxide in the analysis of a powder residue, I instituted the following experiments:

6.157 grams potassic sulphate and 8.541 grams of potassic carbonate were dissolved in 100 cub. centims. of water; the solution filled the space of 103.5 cub. centims.

10 cub. centims. of this liquid were mixed with 5 cub. centims. of a solution containing:

Potassium	0.389 gram.
Sulphur	0.498 "

or 3.12 atoms of sulphur for every 2 atoms of potassium.

The solution so prepared was then digested for two days with previously ignited cupric oxide in a well-stoppered bottle, at ordinary temperatures.

The mixture appeared brown, but became decolorized at 35° C.

The contents of the bottle were placed upon a filter; the black oxide and sulphide were well washed with boiling water, and both, filtrate and wash water united, were kept in a stoppered bottle. They filled the space of 578 cub. centims.

111 cub. centims. of the filtrate required 3.7 cub. centims. of the iodine solution.

192 cub. centims. of the filtrate required 6.3 cub. centims. iodine liquid. Hence, the entire filtrate contained 0.3623 gram of potassic hyposulphite.

* Pogg. Ann., Bd. cxxii, p. 408.

91 cub. centims. of the filtrate acidulated with hydric chloride, boiled for some minutes, separated from precipitated sulphur by filtration, and mixed with baric chloride, gave a precipitate of baric sulphate weighing 0.158 gram. The whole filtrate therefore contains 0.749 gram of potassic sulphate.

91 cub. centims. of the filtrate, acidulated with hydric chloride and evaporated to dryness, gave, after treatment of the residue with hydric sulphate, 0.395 gram potassic sulphate. From this number it follows that the entire filtrate contained 1.124 grams of potassium.

91 cub. centims. of the filtrate gave, with manganous sulphate, a precipitate, which generated with dilute hydric sulphate 0.042 gram of carbonic acid. 578 cub. centims. of the filtrate contain 0.266 gram carbonic acid, corresponding to 0.834 gram potassic carbonate.

From the solution of the precipitate caused by manganous sulphate, 0.094 gram of Mn_3O_4 was obtained, corresponding to 0.597 gram for the entire filtrate; 0.461 gram of this is derived from manganous carbonate, the remainder, 0.136 gram of Mn_3O_4, from the manganous hydrate precipitated by potassic hydrate. 0.136 gram of Mn_3O_4 corresponds to 0.139 gram of potassium or 0.310 gram of K_2S_3. The black cupric oxide and sulphide was dissolved in concentrated hydric nitrate and the solution precipitated by baric chloride; the weight of the baric sulphate was found to be 2.754 grams.

The following table contains the results of these experiments:

	Composition of the original solution.	Found by analysis.
Potassic carbonate	0.829	0.834
" sulphate	0.597	0.749
" tersulphide	0.887	0.310
" hyposulphite . . .	0.000	0.362
Potassium	1.124	1.124
Sulphur in CuO	0.000	0.378
" in $K_2S_2O_3$	0.000	0.122

A considerable error attaches to the determination of the sulphur. The cupric oxide had been ignited in a Hessian crucible. From this, it appears, it became contaminated with silica and alumina. The baric sulphate, precipitated from the solution of the cupric oxide in hydric nitrate by baric chloride, contained a copper compound which I regard as a silicate, since it could not be got rid of even after long-continued boiling with hydric chloride.

The analysis gives quite a wrong idea of the composition of the original solution. Not only is a portion of the potassic tersulphide converted into hyposulphite, it even appears that some has been oxidized into sulphate.

The following experiments prove the absence of sulphates in the reagents used for the above determinations.

15 cub. centims. of solution of potassic tersulphide, acidulated with hydric chloride, boiled, filtered and precipitated with baric chloride gave only 0.0005 gram baric sulphate. 80 grams of cupric oxide were dissolved in hydric chloride and the solution mixed with 1 gram of baric chloride; even after two days' standing no precipitate could be observed.

0.854 gram potassic carbonate, examined in a similar manner, was found to contain only 0.0007 gram of sulphate.

1 gram of sodic hyposulphite in 100 cub. centims. of water gave with barium chloride a crystalline precipitate which proved to be completely soluble in boiling water. Baric chloride, added to the water used in the experiments, and hydric chloride caused no precipitate.

1 gram of sodium hyposulphite was dissolved in 200 cub. centims. of water, hydric chloride added, and the solution boiled during three-quarters of an hour. Baric chloride precipitated 0.022 gram of baric sulphate. Another similar experiment yielded 0.028 gram baric sulphate.

From these experiments it is clear that in a solution containing hyposulphites and sulphates, the latter cannot accurately be determined by the ordinary method. The error from this source is, however, not sufficiently great to account for the discrepancy between the sulphate taken and found in the experiment described on page 18, and exhibited in the table given on that page.

Accordingly, it appears probable that by the action of cupric oxide upon potassic tersulphide, in *presence of potassic carbonate*, not only potassic hyposulphite but also a potassic sulphate is formed.

15 cub. centims. of a solution of potassic sulphide were acidulated by addition of hydric chloride, and by boiling and filtration were separated from the precipitated sulphur. The potassic chloride left, after evaporation of the filtrate from the sulphur, was converted, by means of hydric sulphate, into potassic sulphate. The weight of this salt was found to be 2.554 grams.

5 cub. centims. of potassic sulphide solution, mixed with potassic hydrate and oxidized by chlorine, yielded 3.58 grams of baric sulphate. 10 cub. centims. of potassic sulphide solution, precipitated by zinc sulphate, and the filtrate from the zinc sulphide examined by means of iodine solution for hyposulphites, gave numbers which indicated in 15 cub. centims. of the sulphide solution 0.114 gram of potassic hyposulphite. Sulphuric acid was not found in the sulphide solution.

15 cub. centims. of potassic sulphide solution, out of the same bottle from which the quantities used in the above experiments had been taken, were mixed with solutions of 1.188 grams of potassic sulphate, and of 1.650 grams of potassic carbonate.

The mixture so prepared had the following composition:

	Grams.		Grams.
Potassic carbonate . . .	1.650		
" sulphate . . .	1.188		
" sulphide . . .	2.534	Sulphur	1.4366
		Potassium . . .	1.0977
" hyposulphite . .	0.114	Sulphur	0.0384
		Potassium . . .	0.0468

It was digested for a few days in a closed flask with 40 grams of cupric oxide at common temperatures, and finally decolorized by the raising of its temperature for a short time to 35°C.

The contents of the flask were placed upon a filter and the oxide and sulphide washed with hot water. The volume of filtrate and wash-water measured 1081 cub. centims.

The analysis of the liquid gave the following results:

200 cub. centims. gave 0.394 gram of baric sulphate; according to these numbers 1081 cub. centims. contain 1.589 grams of potassic sulphate.

312 cub. centims. were precipitated with manganous sulphate. From the precipitate so obtained, 0.140 gram of carbonic acid was developed by means of sulphuric acid, and 0.443 gram of Mn_3O_4, prepared by the usual method. Hence, 1081 cub. centims. of filtrate contain 1.521 grams of potassic carbonate and 0.708 gram of potassium in the form of hydrate.

139 cub. centims. of the liquid required 6.4 cub. centims. of iodine solution. Therefore, 1081 cub. centims. contain 0.945 gram of potassic hyposulphite.

200 cub. centims., evaporated with concentrated sulphuric acid, gave 1.069 grams of potassic sulphate, containing 0.4793 gram of potassium, or in 1081 cub. centims. 2.590 grams of potassium.

From these data we find the following composition for the solution:

	Composition of original solution.	Composition according to analysis.
Potassic carbonate . .	1.650	1.521
" sulphate . .	1.188	1.589
" sulphide . .	2.534 { S = 1.4366, K = 1.0977 }	1.633 { S = 0.925, K = 0.708 }
" hyposulphite .	0.114 { S = 0.0384, K = 0.0468 }	0.945 { S = 0.318, K = 0.387 }
Potassium	2.609	2.590

The mixture of cupric oxide and sulphide, dissolved in concentrated nitric acid yielded 8.16 grams of baric sulphate, corresponding to 1.120 grams of sulphur.

	Sulphur.	
	Contained in original solution	Found by analysis.
Potassic sulphate	0.2180	0.291
" sulphide	1.4366	..
" hyposulphite	0.0384	0.318
" Cupric oxide	0.0000	1.120
	1.693	1.729

From these experiments we conclude that by treatment of a solution containing potassic tersulphide, carbonate, and sulphate with cupric oxide, not only potassic hyposulphite, but also potassic sulphate is formed.

Experiments with Potassic Monosulphide.

A solution of 5 grams of pure potassic hydrate, in 100 cub. centims. of water, was divided into two equal parts; one of these was saturated with sulphuretted hydrogen and then mixed with the other.

20 cub. centims. of this solution gave, after evaporation with hydric chloride, 1.1015 grams of neutral potassic chloride, corresponding to 0.812 gram of potassic monosulphide (K_2S).

20 cub. centims. of the solution of the monosulphide were mixed with 2.219 grams of potassic carbonate and 0.950 gram of sulphate, and the mixture digested with pure cupric oxide at common temperatures, in a stoppered bottle, until all the potassic sulphide had been decomposed.

The contents of the bottle were treated in the same manner as in former experiments.

The filtrate of the cupric oxide measured 415 cub. centims.

160 cub. centims. required 2.1 cub. centims. of the iodine solution; therefore we have, in 415 cub. centims. of the filtrate, 0.103 gram of potassic hyposulphite.

It was ascertained, by special experiment, that the original potassic monosulphide did not contain hyposulphite.

60 cub. centims. of the liquid gave 0.185 gram of baric sulphate, corresponding to 0.953 gram of potassic sulphate in 415 cub. centims. of the filtrate.

100 cub. centims. gave with manganous sulphate a precipitate from which 0.174 gram of carbonic acid and 0.428 gram of Mn_3O_4 were obtained. It follows from these numbers that 415 cub. centims. of filtrate contain 0.758 gram of monosulphide and 2.261 grams of carbonate of potassium.

40 cub. centims. of the filtrate evaporated with hydric chloride, and the remaining potassic chloride converted by means of hydric sulphate into potassic sulphate, gave 0.482 gram neutral potassic sulphate. Hence, 415 cub. centims. contain 2.238 grams of potassium.

From the solution of the cupric oxide and sulphide in concentrated hydric nitrate, 1.684 grams of baric sulphate were precipitated; 1.684 grams of baric sulphate contain 0.231 gram of sulphur.

	Composition of original substance.	Found by analysis.
Potassic carbonate, . . .	2.219	2.261
" sulphate, . . .	0.950	0.953
" monosulphide, .	0.812 { K = 0.5765 S = 0.236	0.758 { K = 0.538 S = 0.220
" hyposulphite, .	0.000	0.103 S = 0.034
Potassium, ...	2.255	2.238
Sulphur in cupric oxide, .	0.000	0.231

From these experiments it follows, as a general result, that if a solution containing potassic sulphate, carbonate and mono- ter- or pentasulphide of potassium is digested with pure cupric oxide, the determination of the potassic carbonate yields in all cases a nearly correct result; also for the sulphate an accurate value is obtained in a solution which contains the sulphide as monosulphide, but the numbers found for potassic sulphides are always incorrect. The potas-

sium hyposulphite is formed by the action of cupric oxide upon pentasulphide of potassium in such quantities that a convenient method for the preparation of the salt might be based on the reaction.

Probably all the potassic hyposulphite which was found in powder residues by Bunsen and Schischkoff's method of analysis, was formed during the analytical operations by the oxidation of potassic sulphide by the oxygen of the cupric oxide. At all events, we cannot assume that potassic hyposulphite is one of the products of the explosion of gunpowder, because at 225° C. it decomposes, according to Pape, into potassic sulphate and pentasulphide, and because in later experiments, in which zinc chloride was used instead of cupric oxide, Noble and Abel found very little potassic hyposulphite. We are, therefore, justified in replacing the hyposulphite of the analyses of Noble and Abel by its equivalent quantity of potassic sulphide.

The values found by means of Bunsen and Schischkoff's method for the potassic sulphate would be correct if the powder residues contained only potassic monosulphide. But as, according to Linck's and Noble and Abel's experiments, they contain one of the higher sulphides, it is not improbable that a portion of the sulphate observed has been formed during the treatment with cupric oxide from one of the said sulphides, or by the decomposition of potassic hyposulphite during the process of analysis.

The following considerations indicate how this possible error can be corrected:

If powder is burnt in the apparatus of Noble and Abel, all the oxygen of the decomposed saltpetre is incorporated in the potassic carbonate and sulphate, the carbonic acid and oxide, and these, together with the potassic sulphide, nitrogen and free sulphur amount to about 96 per cent. of the exploded powder. The following calculation leads to the conclusion that the oxygen of the charcoal and of the moisture in the powder does not enter into the composition of the principal products of explosion, but is eliminated in union with hydrogen in the form of water.

According to analysis, the composition of the F. G. powder is represented by the symbols

$$16KNO_3+0.044K_2SO_4+6.88S+20.81C+10.78H+3.52O$$

if ash and moisture of the charcoal are left out of consideration. In Experiment 17 of Noble and Abel the hydrogen in ammonic carbon-

ate, sulphuretted hydrogen, and in a free state, added together is equal to 4.1 atoms. This number deducted from 10.78 atoms, the hydrogen of the charcoal, leaves as difference 6.68 atoms. These 6.68 atoms of hydrogen must have formed water, for which operation 3.34 atoms of oxygen, or almost the exact quantity contained in the charcoal, is required.

Also the moisture of the powder cannot have contributed any oxygen, because if it had, an equivalent quantity of hydrogen ought to have been set free, or entered into combination with nitrogen, carbon, or sulphur. And as in all other experiments of Noble and Abel, executed with F. G. powder from Waltham Abbey, the number of atoms of hydrogen, free or combined, which occur amongst the products of combustion, is less than 4.1, it follows that in these other experiments also the oxygen of the charcoal or of the moisture of the powder has taken no part in the explosion. And finally, since several hundred grams of powder were exploded in a *hermetically* closed steel cylinder, oxygen from the atmosphere cannot have entered into the composition of products of combustion of the powder.

If, then, we find in one of the experiments, after the potassic hyposulphite has been replaced by its equivalent of potassic sulphide, that the sum of the quantities of oxygen contained in the potassic carbonate and sulphate, carbonic acid, and oxide exceeds the oxygen derived from the decomposed saltpetre, we may assume that this excess of oxygen is owing to some sulphate which had been formed during the process of analysis, and accordingly we shall be justified in deducting this excess of sulphate from the total quantity found.

The errors which have been explained on p. 12, due to the mode of calculation, will compensate each other, if the *mean of all the experimental results* be taken.

If all these corrections are carried out we obtain in the form of a chemical equation an approximately correct expression of the metamorphosis of the powders of Waltham Abbey. This equation, deduced from the 31 experiments published by Noble and Abel, is:

$$\left.\begin{array}{l} 4.98K_2CO_3 + 13.13CO_2 + 0.84S \\ +0.90K_2SO_4 + 3.23CO \quad +0.67H_2S \\ +2.10K_2S_2 \quad +17.34N \end{array}\right\} = \left\{\begin{array}{l} 16KNO_3 + 1.34N \\ +21.35C + 1.34H \\ +6.63S \end{array}\right\} \text{(I)}$$

The powder constituents on the right-hand side of the sign of equality have been calculated from the composition of the products of explosion.

The same constituents, as found by the direct analysis of the powders, are represented by the symbols:

$$16KNO_3 + 21.18C + 6.63S$$

which are in close agreement with those deduced from the products of explosion. Powder of this composition, burnt according to the method of Noble and Abel, will form the products of explosion in quantities as represented by equation (I), if the small quantities of secondary products arising from the presence of hydrogen in charcoal, such as marsh gas, ammonia, and free hydrogen, are neglected.

The sulphuretted hydrogen is either the product of the direct union of hydrogen and sulphur at comparatively low temperatures, or of the action of carbonic acid and water upon potassic sulphide. In either case its formation has no direct connection with the explosion, and it ought to be likewise omitted from an equation representing the metamorphosis of gunpowder.

0.84 atom of sulphur is represented as free, because there are no data to show how much sulphur has united with the iron of the apparatus.

It is usual to represent the potassic sulphide as monosulphide. Further on it will be shown that this is not correct, but that disulphide is really produced.

We may then replace equation (I) by the more simple one,

$$16KNO_3 + 21C + 5S = \left.\begin{array}{l} 5K_2CO_3 + 13CO_2 \\ 1K_2SO_4 + 3CO \\ 2K_2S_2 + 8N_2 \end{array}\right\} \quad . \quad . \quad . \quad . \quad . \quad (II)$$

A portion of the sulphur of the powder has united with hydrogen and iron, hence the difference of sulphur in equations (I) and (II).

A powder consisting of

$$16KNO_3 + 21C + 5S$$

exploded according to the method of Noble and Abel in a vessel the substance of which is not attacked by the products of combustion ought, *cæteris paribus*, to yield the products of explosion always in the proportions represented in equation (II).

Under very great pressures the amount of carbonic oxide appears to diminish to a small extent; this variation of the carbonic oxide has, however, only a slight influence on the other products, amounting in the case of potassic carbonate, potassic sulphate, and potassic disulphide generally to less than 0.1 of a molecule. (See note, p. 4.)

Equation (II) expresses only the quantitative relations between the powder constituents and the products of explosion; the reactions which occur during explosion, which of them are simultaneous, and the order in which they succeed each other have still to be determined.

The solid products of explosion possess the composition and the properties of liver of sulphur prepared with an insufficient quantity of sulphur. We can conceive that, at first, all the potassium of the saltpetre forms with carbon and oxygen potassic carbonate, and that, in another stage, sulphur acts on the potassic carbonate and produces the mixture known as the solid powder residue. Or we may conceive that potassic sulphate is the first product, and that this is afterwards reduced by carbon to potassic disulphide and carbonate. Both conceptions would lead to the same results.

The experiments of Karolyi,* executed more than 17 years ago, contain the key to a chemical theory of gunpowder, and allow us to form an idea of the nature of the reactions, and the order in which they follow each other during the combustion of powder. He proposed to himself to decide by experiment whether or not the nature of the products and their relative quantities are dependent on the pressure which obtains during explosion. Craig† had asserted that under great pressure, such as would exist during the explosion in a piece of ordnance, much more potassic sulphide was formed than had been obtained by Bunsen and Schischkoff under ordinary atmospheric pressure. Karolyi took 36.836 grams of Austrian cannon powder, which had, according to his opinion, a composition similar to that of the powder employed by Bunsen and Schischkoff, and enclosed the same in a small metallic cylinder, suspended in the centre of a 60-pounder hermetically closed shell. The air was then pumped out of the shell by means of an air-pump, and the powder exploded by an electric current. As soon as the pressure of the gases in the cylinder had attained a certain magnitude the cylinder burst, and its contents were scattered about the space of the exhausted shell.

The capacity of the shell and the amount of powder had been so adjusted that after explosion the gases in the shell should possess a tension of about 1.5 atmospheres; they were allowed to escape into tubes and sealed up for analysis. The solid products, which were

* Pogg. Ann., Bd. cxviii, p. 544.

† Silliman's Am. J. [2], vol. xxxi, p. 429; Chem. News, vol. iv, p. 18.

removed from the shell by means of water, as well as the gases, were examined by the methods of Bunsen.

A similar experiment was made with 34.153 grams of rifle powder.

Composition of the Powders.

	Cannon powder.	Rifle powder.
Saltpetre	73.78	77.15
Sulphur	12.80	8.63
Charcoal—		
Carbon	10.88	11.78
Hydrogen	0.38	0.42
Oxygen	1.82	1.79
Ash	0.31	0.28

Composition of the Products of Explosion.

	Cannon powder. Grams.	Rifle powder. Grams.
Potassic carbonate	7.14	7.096
" sulphate	13.61	12.354
" hyposulphite	1.04	0.605
" sulphide	0.04	0.000
Carbonic acid	6.40	7.442
" oxide	0.97	0.504
Nitrogen	3.60	3.432
Hydrogen	0.04	0.047
Marsh gas	0.15	0.167
Sulphuretted hydrogen	0.10	0.079
Carbon	0.94	0.887
Sulphur	1.73	0.397
Ammonic carbonate	0.99	0.908
Loss	0.08	0 235

Cannon powder gave 30.77 per cent. of gas and 69.25 per cent. solid residue. Rifle powder gave 34.86 per cent. of gas and 65.14 per cent. solid residue.

Karolyi, comparing his results with those of Bunsen and Schischkoff, arrives at the conclusion that the nature and quantities of the products of explosion are not much influenced by the conditions under which the combustion takes p ace, but that the composition of the powder determines in a great measure the proportions in which the products of explosion are formed. Besides this, he deduces no

other conclusions from his experiments. Karolyi's observations do not support Craig's assertion; the pressure in the metallic cylinder before explosion must have been great, yet very little or no potassic sulphide has been formed.

A few years later (1869) Fedorow* published the results of some experiments executed by him on the explosion of gunpowder. He, like Craig, concludes that under high pressure more potassic sulphide is produced than would be formed by the same powder under lower pressures.

The experiments of Fedorow, however, do not prove anything of the kind. He fired powder from a pistol and from a 9-pounder cannon, and it appears that the solid products of the powder fired from the pistol were collected in a glass tube. A charge of 0.75 gram of powder gave a residue with proportionally more potassic sulphate and less of potassic sulphide than one of 1.5 grams, and relatively still smaller was the potassic sulphate and greater the sulphide in the residue obtained by the firing of 3 lbs. of powder from the cannon.

M. Fedorow concludes: A smaller amount of powder remains unconsumed, less potassic sulphate, but more sulphide and carbonate are formed under higher than under lower pressures. Time acts like pressure. If the combustion of the powder is retarded the same effects follow as if the pressure had been increased. A charge of 1.5 grams of a mixture consisting of 100 parts of meal powder, and 0.5 part of stearic acid, gave a residue with less potassic sulphate, but with more carbonate and hyposulphite than a similar charge of ordinary powder would have done.

Potassic sulphide is, as is well known, a substance endowed with great attraction for oxygen, not only at high, but also at ordinary temperatures. It appears that the air was not excluded from the glass tube into which M. Fedorow fired his charges for the collection of the solid residues. A greater percentage of the potassium sulphide formed by a small charge, than of the sulphide of the products of a larger charge will in this manner be oxidized.

It thus appears that M. Fedorow's experiments can be explained without reference to pressure. But as far as the retardation of the combustion by stearic acid is concerned, we cannot ascribe to retard-

*Zeitschrift für analytische Chemie, Bd. ix., p. 127; Strecker, Jahresbericht, 1869, p. 1059.

ation an effect which is due to the stearic acid itself. Stearic acid at a red heat reduces potassic sulphate to sulphide and probably carbonate.

M. Fedorow could not collect and examine the gases.

The experiments of Fedorow do not establish a relation between pressure and the nature and quantities of the products of explosion, and, consequently, do not invalidate the conclusions of Karolyi, as stated on pp. 26 and 27.

We will now proceed to explain, by means of the analytical results of Karolyi, some of the reactions which take place during the combustion of gunpowder. For this purpose it will be desirable to express the composition of the Austrian powders, and the products of explosion, by chemical formulæ.

Composition of the Powders.

	Cannon Powder.	Rifle Powder.
Saltpetre	16.00 mols.	16.00 mols.
Sulphur	8.70 atoms.	5.66 atoms.
Carbon	19.80 "	20.57 "
Hydrogen	8.32 "	8.80 "
Oxygen	2.50 "	2.34 "

Composition of the Products of Combustion of Quantities of Powder which contain 16 mols. of Saltpetre.

	Cannon Powder.	Rifle Powder.
Potassic carbonate	3.05 mols.	3.27 mols.
" sulphate	4.61 "	4.52 "
" hyposulphite	0.31 "	0.20 "
" sulphide	0.01 "	0.00 "
Carbonic acid*	9.23 "	11.46 "
" oxide	2.04 "	1.15 "
Nitrogen	7.55 "	8.06 "
Sulphuretted hydrogen	0.17 "	0.14 "
Hydrogen	2.36 atoms.	3.01 atoms.
Marsh gas	0.55 mol.	0.67 mol.
Ammonia	0.92 "	0.91 "
Carbon	4.61 atoms.	4.74 atoms.
Sulphur	3.16 "	0.79 "

*Inclusive of the carbonic acid combined with ammonia.

Calculated from the products of combustion, we obtain for

Cannon powder . . . $16KNO_3 + \underbrace{19.48C + 7.66H}_{\text{Charcoal.}} + 8.58S$

Rifle powder . . . . $16KNO_3 + \underbrace{21.4C + 8.7H}_{\text{Charcoal.}} + 5.68S + 1.04N.$

The potassic carbonate, potassic sulphate, potassic hyposulphite, and potassic sulphide, the nitrogen, carbonic acid, and carbonic oxide added together, amount in the case of the cannon powder to 89.6, and in that of the rifle powder to 92.0 per cent. of the exploded powder. 7.2 per cent of carbon and sulphur of the cannon powder and 3.7 per cent. of the same elements of the rifle powder, remained free at the end of the explosion. The sum of all the other products, therefore, does not amount to more than 3 or 4 per cent., and as, with the exception of the nitrogen in the ammonia, no constituents of the saltpetre occur in them, they may be regarded as merely accessory products not directly concerned in the explosion.

As the composition of the Austrian service powders does not differ much from that of the powders of Waltham Abbey, it will be interesting to contrast the results of Karolyi with those obtained by Noble and Abel.

Remarkable differences will be observed if equation (I), page 23, is compared with the composition of the products of combustion observed by Karolyi and represented by means of chemical symbols as above. Equation (I), as well as Karolyi's results, are calculated for quantities of powder containing 16 mols. KNO_3.

Noble and Abel, according to equation (I), found about a quarter of the potassium of the decomposed saltpetre as potassic sulphide, whereas in Karolyi's experiments the sum of the potassium in the hyposulphite, and in the sulphide of the products of combustion of cannon powder amounted to only $\frac{1}{20}$th, and in that of the rifle powder only to $\frac{1}{40}$th of the potassium of the saltpetre of the exploded powder. It seems to follow that the production of such small quantities of potassic hyposulphite and sulphide cannot be the direct result of the chief reactions of the explosion. Karolyi obtained much more potassic sulphate and less potassic carbonate than the English chemists; a considerable quantity of the carbon of his powders remained unconsumed, whilst in Noble and Abel's experiments, as a rule, every trace of this element was burnt, although the English

powders contain somewhat more carbon than the Austrian. Similar differences occur between the results obtained with the gaseous products. The gases obtained by Karolyi were combustible, those of Noble and Abel were not. The gases from the Austrian powders contained more hydrogen and marsh gas and less sulphuretted hydrogen than those from the mixtures of Waltham Abbey.

	Mean percentage by volume.	
	Austrian.	Waltham Abbey.
Hydrogen	6.41	2.50
Marsh gas	2.86	0.31
Sulphuretted hydrogen . . .	0.76	2.56

Karolyi inclosed his powders in a thin brass cylinder hermetically closed, and ignited the charge by means of a galvanic current. As soon as the tension of the gases developed by the combustion had reached a certain magnitude the metal cylinder exploded, and its contents were scattered against the cold sides of the exhausted 60-pounder shell. Thus the combustion of the powder was interrupted before its completion. The correctness of this view is rendered apparent if the effect is considered which would have followed if the products of Karolyi had remained in contact for some time at a red heat. The free carbon and hydrogen, and the constituents of the marsh gas would have been burnt at the expense of the oxygen of the potassic sulphate; the quantity of the latter would have been diminished and that of the sulphide increased, the free sulphur would have decomposed potassic carbonate with production of potassic sulphate and sulphide; in short, the products of combustion would have formed in similar proportions as we find them in Noble and Abel's experiments. The products of several hundred grams of powder remained in a fluid condition at a white heat in Noble and Abel's steel cylinder from 60 to 100 seconds in contact, whereas the 36 grams of burning powder were scattered after the explosion of Karolyi's brass cylinders over the cold sides of a large iron shell, and their combustion occupied only a very small fraction of a second. The reactions between the powder constituents had time to complete themselves in Noble and Abel's steel cylinder, but they had not in Karolyi's small brass vessel. And although the time of the combustion in the experiments of the last-named chemist was very short, less than one second, we find all the saltpetre of the powder decomposed and its constituents incorporated in the potassium salts, carbonic oxide and carbonic acid, or set free as nitrogen.

At the same time two of the potassium salts, the hyposulphite and sulphide, occur in such small quantities that we may regard them as secondary products, not connected with the chief reactions of the explosion, and accordingly neglect them.

Hence we have, as chief products formed in Karolyi's experiments: potassic sulphate and potassic carbonate, carbonic acid and nitrogen, and perhaps carbonic oxide.

The combustion of gunpowder accordingly consists of two distinct stages; a process of oxidation, which is finished in a very short time, occupying only a very small fraction of a second, and causing the explosion, and during which potassium carbonate and sulphate, carbonic acid, some carbonic oxide and nitrogen are produced, and a process of reduction, which succeeds the process of oxidation and requires a comparatively long time for its completion. As the oxygen of the saltpetre is not sufficient to oxidize all the carbon to carbonic, and all the sulphur to sulphuric acid, a portion of the carbon and a portion of the sulphur are left free at the end of the process of oxidation. The carbon so left free reduces, during the second stage of the combustion, potassic sulphate, and the free sulphur decomposes potassic carbonate. Hydrogen and marsh gas, which are formed by the action of heat upon charcoal, likewise reduce potassic sulphate, and some hydrogen combines with sulphur, forming sulphuretted hydrogen.

Great variations of pressure appear to affect the proportions of the different products in a very slight degree, so that it may be regarded as doubtful whether pressure has any influence on them.

Karolyi's experiments happen to be arranged in such a manner that the combustion of his powders could only proceed to the end of the first and the commencement of the second stage; in Noble and Abel's explosions, the reactions of the second stage were also completed.

This view of the combustion of gunpowder explains not only the experiments of Noble, Abel, and Karolyi, but is also in perfect accordance with the thermo-chemical relations of the products of explosion.

The heat of formation of a molecule of potassic sulphate is much greater than that of one of potassic sulphide, hence the production of the former is to be expected during explosion. In short, the formation of the molecules of potassic carbonate, potassic sulphate, and carbonic acid is accompanied by the greatest evolution of heat.

Karolyi examined the products of explosion according to Bunsen and Schischkoff's method, which does not yield exact values for

potassic sulphide and sulphate. The errors arising from this source will, however, be very small, if the potassic sulphide in the original powder residue is small. The small amount of potassic hyposulphite found by Karolyi proves that the products of combustion contained, in his experiments, very little potassic sulphide. As the potassic hyposulphite must be regarded as a product of oxidation of the potassic sulphide, it has been replaced in the following calculations by its equivalent of potassic sulphide. Nevertheless, the quantity of the latter does not exceed 0.32 of a molecule, hence the error caused by the method of analysis may be neglected.

We will now take the chief products of explosion observed by Karolyi, and calculate from their composition the quantities of powder constituents which took part in their formation, and arrange the results in form of equations.

Cannon Powder.			Rifle Powder.		
3.05 K_2CO_3		16 KNO_3	3.30 K_2CO_3		16 KNO_3
4.62 K_2SO_4		14.32 C	4.49 K_2SO_4		15.94 C
0.33 K_2S_2	=	5.28 S	0.20 K_2S_2	=	4.89 S
9.23 CO_2		−0.9 N	11.49 CO_2		3.99 O
2.04 CO		0.13 O	1.15 CO		
7.55 N_2			8.00 N_2		

The entire quantity of saltpetre contained in the powders taken for these experiments was decomposed, and its constituents, with the exception of very small quantities of potassium and nitrogen, in potassic sulphocyan te and ammonia, reappear in the above chief products. The cannon powder contains for every 16 mols. of KNO_3 about 3 atoms of sulphur more than the rifle powder (p. 29). Nevertheless, during the first stage of the combustion the quantities of sulphur consumed in the formation of potassic sulphate are nearly the same in the experiments with both powders, and the potassic carbonate and disulphide are also almost identical.

The ratios of the oxygen in the potassic carbonate, sulphate, and carbonic acid are as follows:

	Oxygen.		
	K_2CO_3	K_2SO_4	CO_2
Cannon powder .	9.15	18.44	18.46
	1	2	2
Rifle powder . .	9.90	17.96	22.98
	1	1.81	2.33

The amount of oxygen in the products of explosion of the rifle powder has been found about 1.2 per cent. too high, consequently an error attaches to one or more of the analytical determinations.

The metamorphosis of the cannon powder during the first stage of the combustion can almost exactly, that of the rifle powder approximately, be represented by the equation

$$10(KNO_3)+8C+3S=2(K_2CO_3)+3K_2SO_4)+6(CO_2)+5(N_2) \quad \text{(III)}$$

It is worthy of notice that the ratios of the oxygen in the three principal products, potassic carbonate, potassic sulphate, and carbonic acid, are, according to equation (III), of all possible ratios the most simple, if these products are to be formed by the combustion of a mixture of saltpetre, carbon and sulphur.

From these considerations it appears to follow that during the explosion of gunpowder, or the first stage of its combustion, the constituents of powders which differ in their composition will act on each other in certain fixed stoichiometrical proportions.

It may be assumed as highly probable that of the infinite number of mixtures which can be prepared from saltpetre, carbon, and sulphur, some will be more combustible than others, and, among the more combustible mixtures, one will be found containing the constituents in proportions most favorable for their transformation into the chief products of explosion. In this most combustible mixture the number of the molecules of saltpetre and of the atoms of carbon and sulphur will probably stand in simple arithmetical relations to each other, and if a mixture containing the constituents in other proportions be ignited, they will tend to react on each other in the stoichiometrical proportions of the most combustible mixture.

Equation (III) can be transformed into:

$$16KNO_3+12.8C+4.8S=3.2K_2CO_3+4.8K_2SO_4+9.6CO_2+8N_2$$

and as during the first stage of the combustion some carbonic oxide is probably also formed, we may write the equation instead

$$16KNO_3+13C+5S=3K_2CO_3+5K_2SO_4+9CO_2+CO+8N_2 \quad \text{(IV)}$$

This equation explains the experiments of Karolyi in a very satisfactory manner.

If the reactions went a little beyond the first stage of the combustion, and we add to the left of the sign of equality 1.32 atoms of carbon, which would reduce some potassic sulphate with formation of potassic sulphide and carbonate, carbonic acid and oxide, according

to equations which will be given afterwards, numbers are obtained which are almost identical with those calculated from Karolyi's observations on the products of explosion of cannon powder (p. 32). The same remark applies to the products of the rifle powder, except the carbonic acid.

The excess of oxygen found in the products of rifle powder indicates that some error has occurred in the determinations of these products, and it seems to have influenced, almost exclusively, the carbonic acid. If the quantity of this substance is calculated according to the available oxygen of the decomposed saltpetre, a number is obtained which agrees very well with equation (IV).

From the foregoing observations it follows that powders of the composition of the Austrian service powders—

$$16KNO_3 + 19.8C + 8.7S$$
$$\text{and } 16KNO_3 + 20.57C + 5.66S$$

burn during the first stage of the metamorphosis according to the equation:

$$16KNO_3 + 13C + 5S = 3K_2CO_3 + 5K_2SO_4 + 9CO_2 + CO + 8N_2$$

and that the carbon and sulphur which the powders contain, beyond the quantities required by this equation, remain free.

The very combustible sporting powder of Bunsen and Schischkoff contained

$$16KNO_3 + 13.3C + 6.3S$$

Therefore, it will be seen that the constituents of the service powders react upon each other during the first stage of the explosion nearly in the same stoichiometrical quantities in which they are contained in the more highly combustible sporting powder.

If it be correct that equation (IV) represents proportions of saltpetre, carbon, and sulphur, in which these substances will burn with greater facility than they do in the proportions of the service powders, then we can by means of equation (IV) calculate the composition of a powder which shall be distinguished by its great combustibility.

Besides saltpetre, carbon and sulphur, hydrogen, oxygen, ash, and moisture are contained in gunpowder. The weight of these latter constituents is about 4 per cent. of the mixture. If we add 4 per cent. to the quantities represented by the symbols

$$16KNO_3 + 13C + 5S$$

and consider hydrogen, oxygen, ash, and moisture united with carbon to charcoal, we obtain for the percentage composition of the most combustible mixture

Saltpetre	80.31
Sulphur	7.95
Charcoal	11.74

Sporting powders are required to burn quickly, and the composition of some of them approaches very closely to these theoretical values.

	Saltpetre.	Sulphur.	Charcoal.
English*	79.7	7.8	12.5
French, ...	78.0	10.0	12.0
Bunsen and Schischkoff's powder, .	78.99	9.84	11.17
Sporting powder in the year 1546, .	83.4	8.3	8.3

The heat relations of the products of explosion, as represented by equation

$$16KNO_3 + 13C + 5S = 3K_2CO_3 + 5K_2SO_4 + 9CO_2 + CO + 8N_2,$$

are of special interest.

If we assume for the heat of formation of potassic carbonate, potassic sulphate, and carbonic acid the following values:

$$K_2CO_3 = 279540 \text{ cal.}$$
$$K_2SO_4 = 344640 \text{ "}$$
$$CO_2 = 97000 \text{ "}$$

we obtain

$$3 \times 279540 = 838620$$
$$5 \times 344640 = 1723200$$
$$9 \times 97000 = 873000$$
$$838620 : 1723200 : 873000 = 1 : 2.05 : 1.04$$

or nearly 1 : 2 : 1

ratios which are very remarkable.

The total amount of heat produced by the combustion of $16KNO_3 + 13C + 5S$ according to equation (IV), is = 1563189 cal. The maximum amount of heat is produced by a mixture which contains for every 16 mols. of saltpetre 8 atoms of carbon and 8 atoms of sulphur, according to the equation

$$16KNO_3 + 8C + 8S = 8K_2SO_4 + 8CO_2 + 8N_2$$

and amounts to 1621450 cal.

* Graham-Otto, "Lehrbuch der Chemie," iv edit., ii, p. 211.

Therefore, if the combustion of ordinary service powder takes place during the first stage according to equation (IV), nearly the maximum quantity of heat is obtained which a mixture of saltpetre, sulphur, and carbon can produce. If the question were asked: in what proportions must the constituents of a given mixture of saltpetre, carbon, and sulphur react during the process of explosion, and what must be the ratios of the chief products of explosion, so that on one hand the total quantity of heat developed is as great as possible, and, on the other hand, the amounts of heat produced by the formation of the chief products shall stand to each other in a simple relation? the answer would be: the combustion must take place according to equation (IV).

But not only does this equation correspond to the most simple relations of the heat of formation of the principal products, it likewise requires the most simple distribution of the oxygen of the decomposed saltpetre. If the combustion of a mixture of saltpetre, carbon, and sulphur is to produce potassic carbonate and sulphate, carbonic acid and nitrogen, and if the oxygen of each of the first three products is to stand to the oxygen of the others in the most simple ratios possible, then the mixture must burn according to equation (III), p. 33, and as the proportions expressed by equation (IV) closely approach to those of equation (III), it follows that equation (IV) fulfils all the conditions and consequences explained in the foregoing lines. And, perhaps, these relations are the cause why mixtures of saltpetre, carbon, and sulphur of different composition burn during the first stage of the explosion according to equation (IV), and if they contain more carbon and sulphur than is required by this equation, the excess of the two elements will remain free.

These interesting conclusions I deduce from the analytical data of Karolyi and the corrected results of Noble and Abel's experiments. Their investigations, however, do not give any information about the reactions of the second stage of the combustion of gunpowder, the reduction of potassic sulphate by carbon, and the decomposition of potassic carbonate by sulphur. Hitherto it has been assumed that potassic mono-sulphide is formed; this is, however, a mistake.

According to Berzelius and Mitscherlich,* the products of the decomposition of potassic carbonate by sulphur at a white heat are potassic sulphate and disulphide:

$$4K_2CO_3 + 7S = K_2SO_4 + 3K_2S_2 + 4CO_2$$

* Gmelin-Kraut, "Handbuch der Chemie," Bd. ii, p. 39.

The question we have now to solve is: which of the sulphides of potassium is formed by the action of carbon upon potassic sulphate at a white heat?

Bauer* and Wittstock† obtained potassic carbonate and a polysulphide, but the amount of sulphur in the polysulphide was not determined.

A mixture of

26.5 grams of potassic sulphate
10.54 " " carbonate
2.5 " charcoal

was exposed in a porcelain crucible for half an hour to a temperature approaching white heat. The contents of the crucible dissolved completely in water, forming a deep yellow solution.

20 cub. centims. of this solution acidulated with hydric chloride, gave a copious precipitate of sulphur, and the filtrate of this precipitate left, after evaporation and treatment with hydric sulphate, 2.943 grams of potassic sulphate. The potassium of

1.960 grams potassic sulphate
0.779 " " carbonate

of the salts originally taken, is, accordingly, present in 20 cub. centims. of the solution.

20 cub. centims. of the solution gave by the usual method 1.038 grams of baric sulphate, corresponding to 0.775 gram of potassic sulphate.

19.28 cub. centims. of the same solution placed for some days in contact with 5 grams of cupric oxide and the carbonic acid in the liquid determined according to Bunsen's method gave 0.37 gram of this substance, which corresponds to 1.203 grams of potassic carbonate in 20 cub. centims. of the solution.

1.96 grams of potassic sulphate originally taken contain 0.36 gram of sulphur.

0.775 gram of potassic sulphate found in 20 cub. centims. contains 0.142 gram of sulphur.

Sulphur in potassic sulphide = 0.218 gram.

20 cub. centims. of the solution contain 1.318 grams of potassium.

1.203 grams of potassic carbonate contain 0.680 gram of potassium, and 0.775 gram of potassic sulphate 0.347 gram of potassium; the

* Gmelin-Kraut, "Handbuch der Chemie," Bd. ii, p. 33. † *Ibid.*, p. 33.

difference of 0.291 gram represents the potassium in potassic sulphide.

Hence the potassic sulphide produced by the action of the carbon of the charcoal upon the mixture of potassic sulphate and carbonate contains:

	Gram.
Potassium	0.291
Sulphur	0.218
	0.509

and the composition of the salts in 20 cub. centims. of the solution of the fused mass is:

	Found.	Taken.
Potassic sulphate . . .	0.775	1.960
" carbonate . . .	1.203	0.779
" sulphide . . .	0.509	0.000

The composition of the potassic sulphide can be represented by the symbols

$$K_2S_{1.82}$$

Therefore, potassic sulphate and the carbon of charcoal react, under the conditions of the experiment, principally according to the equation

$$4K_2SO_4 + 7C = 2K_2CO_3 + 2K_2S_2 + 5CO_2.$$

Noble and Abel calculate their potassic sulphide as monosulphide, and in a special column give, as free sulphur, the sulphur not contained in the monosulphide, potassic sulphate and potassic hyposulphite. This so-called free sulphur was in reality contained in the residues partly in union with potassium as disulphide, partly with iron as ferrous sulphide.

If we imagine their free sulphur all combined with their potassic monosulphide, we obtain:

In 15 experiments united to two atoms of potassium, from 1.7 to 2.44 atoms of sulphur.

In seven experiments from 2.44 to 3.00 atoms of sulphur.

And in three experiments from 3.0 to 3.7 atoms of sulphur. The mean of 25 experiments would give us for 2 atoms of potassium 2.42 atoms of sulphur. But as a portion of the so-called free sulphur was in union with iron, it follows that in the powder residues 2 atoms of potassium were on an average combined with less than 2.42 atoms of

sulphur. These numbers, however, apply only to their corrected results.

According to Berzelius and Mitscherlich the action of sulphur upon potassic carbonate at a white heat produces K_2S_2; the reduction of potassic sulphate in presence of carbonate, according to my own experiments, gives $K_2S_{1.82}$; the mean of Noble and Abel's experiments for the composition of the potassic sulphide formed by the explosion of powder in their apparatus is less than 2.42 atoms of sulphur for every 2 atoms of potassium, hence we may conclude that the potassium sulphide formed during the second stage of the combustion of gunpowder is the disulphide, or at least contains the two elements in a proportion closely approaching the proportion in the disulphide. The following considerations confirm this conclusion.

The mean composition of the English service powder is:

$$16KNO_3 + 21.18C + 6.63S.$$

The Austrian rifle powder contains:

$$16KNO_3 + 20.57C + 5.66S$$

The products of combustion of the former are, according to Noble and Abel,

$$4.98K_2CO_3 + 0.90K_2SO_4 + 2.10K_2S + 13.13CO_2 + 3.23CO + 0.84S.$$

Those of the Austrian rifle powder, according to Karolyi, are

$$3.27K_2CO_3 + 4.52K_2SO_4 + 0.2K_2S_2 + 11.46CO_2 + 1.15CO + 4.74C + 0.79S.$$

Karolyi's products contain a considerable amount of free carbon, which element is completely burnt in Noble and Abel's experiments.

If we now assume that Karolyi's products had remained in contact at a high temperature, not a fraction of a second, but from one to two minutes, as was the case in Noble and Abel's experiments, the free carbon would have been oxidized by oxygen contained in potassic sulphate, and the free sulphur would have reacted upon the potassium carbonate, and the final result of these reactions would have been a quantitative relationship between the products similar to that found by Noble and Abel. The potassic carbonate, the potassic disulphide, the carbonic oxide, and carbonic acid would have increased, and the quantity of the potassic sulphate would have diminished. But the

amount of potassic carbonate could not become greater if the reduction of the sulphate took place according to the equation:

$$K_2SO_4 + 2C = K_2S + 2CO_2$$

hence, we must assume the formation of potassic disulphide. If we calculate from the analytical data of Karolyi the proportions of his products on the supposition that the carbon which had remained free had acted on potassic sulphate according to the equation:

$$4K_2SO_4 + 7C = 2K_2CO_3 + 2K_2S_2 + 5CO_2$$

we obtain:

$$4.65K_2CO_3 + 1.12K_2SO_4 + 2.22K_2S_2 + 14.08CO_2 + 2.65CO$$

quantities which are as near those found for the English powders as the composition of the Austrian rifle powder approaches those of Waltham Abbey.

If the potassic hyposulphite found by Bunsen and Schischkoff originated during the analysis of their powder residue, then the latter contained, for 16 mols. of decomposed saltpetre, 0.45 mol. of K_2S_2 and 0.33 mol. of K_2S.

Linck* found, amongst the products of the Würtemberg service powder, only potassic disulphide.

From Noble and Abel's† analysis of the products of English mining powder it would follow that for every 16 mols. of decomposed saltpetre, 4 mols. of K_2S are formed and 5 atoms of sulphur left free; this would give us for the composition of the potassic sulphide 2 atoms of potassium and 2.25 atoms of sulphur.

From these facts we conclude that the second stage of the combustion of gunpowder takes place according to the equations:

$$4K_2CO_3 + 7S = K_2SO_4 + 3K_2S_2 + 4CO_2 \quad . \quad . \quad . \quad . \quad (V)$$
$$4K_2SO_4 + 7C = 2K_2CO_3 + 2K_2S_2 + 5CO_2 \quad . \quad . \quad . \quad . \quad (VI)$$

The possibility of dissociation requires the additional equation

$$K_2CO_3 + K_2S_2 + O_7 = 2K_2SO_4 + CO_2 \quad . \quad . \quad . \quad . \quad (VII)$$

The final results of the reactions represented by equations (III), (IV), (V), (VI) and (VII) can be expressed by one equation.

For this purpose let x, y and z be positive numbers, and a denote how many molecules of carbonic oxide are formed by the combustion

* Ann. der Chemie und Pharm., Bd. cix. (1859), p. 53.

† Phil. Trans. (1880), p. 207.

of a quantity of powder containing x molecules of saltpetre, y atoms of carbon and z atoms of sulphur. The general equation representing the qualitative and quantitative relations between the constituents of a mixture of saltpetre, carbon and sulphur on the one hand, and the products of *complete* combustion on the other, will then be:

$$\left.\begin{aligned} x\mathrm{KNO_3}+y\mathrm{C}+z\mathrm{S} = {} & \tfrac{1}{2\,1\,8}[4x+8y-16z-4a](\mathrm{K_2CO_3}) \\ & +\tfrac{1}{2\,1\,8}[20x-16y+4z+8a](\mathrm{K_2SO_4}) \\ & +\tfrac{1}{2\,1\,8}[-10x+8y+12z-4a](\mathrm{K_2S_2}) \\ & +\tfrac{1}{2\,1\,8}[-4x+20y+16z-24a](\mathrm{CO_2}) \\ & +\tfrac{1}{2}x\mathrm{N_2} \\ & +a\mathrm{CO} \end{aligned}\right\} \quad \text{(VIII)}$$

As far as the application of this equation is concerned, the following remarks are, perhaps, not unnecessary.

The charcoal of gunpowder contains, besides carbon, also oxygen and hydrogen, ash and moisture. The oxygen of the charcoal is, as has already been proved before (pp. 22, 23), eliminated with some of the hydrogen as water. The rest of the hydrogen of the charcoal with nitrogen, carbon and sulphur respectively, forms by-products, the total weight of which, as a rule, does not exceed 2 per cent. of the powder burnt.

The products of combustion, with the exception of those prepared by Noble and Abel, contain always some unburnt carbon and sulphur, and frequently undecomposed saltpetre.

Hence we have:

a. Chief products: $\mathrm{K_2CO_3}$, $\mathrm{K_2SO_4}$, $\mathrm{K_2S_2}$, $\mathrm{CO_2}$, CO, and $\mathrm{N_2}$.
b. By-products: $\mathrm{H_2}$, $\mathrm{H_2S}$, $\mathrm{CH_4}$, $\mathrm{NH_3}$, $\mathrm{H_2O}$, and KCNS.
c. Constituents of powder, not burnt: $\mathrm{KNO_3}$, C, and S.

Equation (VIII) enables us to calculate, from that portion of the powder which produces the chief products (mentioned under *a*), the quantities of these products formed during complete combustion.

We will now proceed to prove, by examples, the correctness of this equation.

Bunsen and Schischkoff found in 1 gram of sporting powder, and in the products of its combustion, the following quantities:

1 gram of powder—

Saltpetre	0.7899
Sulphur	0.0984

Charcoal—	
Carbon	0.0769
Hydrogen	0.0041
Oxygen	0.0307
Chief products of combustion—	
Potassic sulphate	0.4227
" carbonate	0.1264
" hyposulphite	0.0327
" sulphide	0.0213
Carbonic acid*	0.2159
" oxide	0.0094
Nitrogen	0.0998
	0.9282
By-products—	
Potassic sulphocyanate	0.0030
Hydrogen	0.0002
Sulphuretted hydrogen	0.0018
Oxygen	0.0014
Ammonia and water	0.0139
	0.0203
Powder constituents not decomposed or burnt—	
Saltpetre	0.0372
Carbon	0.0073
Sulphur	0.0014
	0.0459
Hence—	
Chief products	0.9282
By-products	0.0203
Unburnt powder	0.0459
	0.9944

If the potassic hyposulphite is replaced by its equivalent of potassic disulphide, the quantities of the chief products expressed in mole-

* Inclusive of the carbonic acid of the ammonic carbonate.

cular weights, and calculated for 16 mols. of decomposed saltpetre, we obtain:

$$1.97K_2CO_3+5.25K_2SO_4+0.45K_2S_2+10.59CO_2+7.7N_2+0.33K_2S+0.71CO.$$

From these symbols we calculate the following composition of the powder:

$$16KNO_3+13.2C+6.48S+0.66O.$$

If now we substitute, in equation (VIII), for x the number 16, for y 13.2, for z 6.5, and for a 0.71, we find for the chief products:

$$2.25K_2CO_3+5.01K_2SO_4+0.74+K_2S_2+10.25CO_2+0.70CO+8N_2$$

numbers which closely agree with those found by experiment.

The powder used by Bunsen and Schischkoff contains, according to analysis:

$$16KNO_3+13.3C+6.3S$$

a composition which is nearly the same as that deduced from the chief products of combustion.

The analytical method in this case causes no appreciable error in the determination of the potassic sulphate. Neither, according to my own analysis, does potassic monosulphide, nor, according to Noble and Abel's analysis of the residues of mining powder, does potassic disulphide produce potassic sulphate by treatment with cupric oxide. Bunsen and Schischkoff's residues contained a mixture of mono- and disulphide, and of both only a comparatively small quantity.

Linck* examined the products of combustion of the Würtemberg service powder according to the method employed by Bunsen and Schischkoff. He obtained the following results:

Composition of the powder—

Saltpetre	0.7470
Sulphur	0.1245
Charcoal—	
Carbon	0.0905
Hydrogen	0.0041
Oxygen	0.0278
Water	0.0060
	0.9999

* Ann. der Chemie und Pharm., Bd. cix., p. 53.

Chief products of combustion—

Potassic sulphate	0.2891
" carbonate	0.1537
" hyposulphite	0.0374
" disulphide	0.0959
Carbonic acid *	0.2345
" oxide	0.0118
Nitrogen	0.0952
	0.9176

By-products—

Potassic sulphocyanate	0.0116
Sulphuretted hydrogen	0.0238
Hydrogen	0.0003
Oxygen	0.0001
Ammonia and water	0.0098
	0.0456

Powder constituents not decomposed or burnt—

Saltpetre	0.0120
Carbon	0.0183
Sulphur	0.0031
	0.0334

Hence—

Chief products	0.9176
By-products	0.0456
Not burnt	0.0334
	0.9966

If we express the quantities of the chief products by means of molecular weights, and calculate how much of each would be formed by the combustion of a quantity of powder containing 16 mols. of saltpetre, we obtain:

$$2.43K_2CO_3 + 3.64K_2SO_4 + 0.43K_2S_2O_3 + 1.47K_2S_2 + 11.71CO_2 + 0.92CO + 14.94N$$

and expressed in powder constituents:

$$16KNO_3 + 15.06C + 7.44S - 1.06N - 0.52O.$$

* Inclusive of the carbonic acid in the ammonic carbonate.

The powder contained, according to analysis:

$$16KNO_3 + 16.3C + 8.4S.$$

The by-products contain no oxygen of the saltpetre, and with the exception of the potassium and nitrogen in the potassic sulphocyanate, and the nitrogen of the ammonia, their elements are derived from the charcoal and sulphur. The chief products should, accordingly, contain all the oxygen of the decomposed saltpetre. This, however, is not the case; 0.52 of an atom is wanting, and if the potassic hyposulphite, as we must assume, has been formed by the oxidizing action of the cupric oxide upon the potassic disulphide, then no less than 1.81 atoms or nearly $\frac{1}{9}$th of the oxygen of the decomposed saltpetre have disappeared. Linck himself finds in the products of combustion 1.75 per cent. or about $\frac{1}{2}\frac{1}{2}$d less oxygen than in the original powder, and this loss of oxygen would have appeared still greater if he had not assumed that the oxygen of the hyposulphite had been derived from saltpetre. On the other hand, Linck finds in the products of explosion 0.71 per cent. or $\frac{1}{12}$th to $\frac{1}{13}$th more of carbon, and 0.9 or $\frac{1}{13}$th to $\frac{1}{14}$th more of sulphur than in the original powder. Accordingly, it follows, either that Linck's powder has not the composition which he ascribes to it, or that some considerable errors attach to the analytical data of the products of explosion. Hence, no near agreement can here be expected between theory and experiment.

If we replace the potassic hyposulphite found, by its equivalent of potassic disulphide, express the quantity of the chief products by molecular weights, and calculate the composition of that portion of the powder which was transformed into the chief products, we obtain

$$16KNO_3 + 15.06C + 7.44S - 1.06N - 1.81O.$$

and if in equation (VIII) we place,

$$x = 16 \qquad y = 15$$
$$z = 7.5 \qquad a = 1.0$$

we find the following theoretical values, which are placed by the side of the experimental numbers:

		Theory.	Experiments.
$16KNO_3$	K_2CO_3 . .	2.14	2.43
$15C$	K_2SO_4 . .	4.21	3.64
$7.5S$	K_2S_2 . . .	1.64	1.90
	CO_2 . . .	11.85	11.71
	CO . . .	1.0	0.92

Some mistake appears to have occurred in the determination of the potassic sulphate and carbonate. The calculation could likewise be carried out in the following manner: The unburnt portion of the powder, and the quantities of the elements contained in the by-products, could be subtracted from the composition of the quantity of powder taken for experiment, and from the rest, the quantities of the products might be calculated according to the equation (VIII). This mode of calculation is in Linck's case not applicable, because large quantities of charcoal remained unburnt, the composition of which is not known. This charcoal having been exposed to the high temperature developed by the combustion of the powder can no longer have had the original composition, but was probably nearly pure carbon.

The composition of the Austrian cannon powder can be represented by the symbols:

$$16KNO_3+19.8C+8.7S$$

if hydrogen, oxygen, ash and moisture of the charcoal are neglected. All the potassium and the oxygen of the decomposed saltpetre reappeared in the chief products of explosion, but more than 4 atoms of carbon and 3 atoms of sulphur remained free. The amount of the sulphide formed by this powder was very small in Karolyi's experiment.

The powder constituents which were transformed into the chief products are represented by the symbols

$$16KNO_3+14.32C+5.28S$$

and 2.04 mols. of CO had been formed (p. 28).

The values of these coefficients substituted for x, y and z in equation (VIII) yield the following theoretical quantities of the chief products of combustion, to which are appended the quantities found by experiment:

		Theory.	Experiments.
$16KNO_3$	K_2CO_3	3.06	3.05
$14.32C$	K_2SO_4	4.59	4.61
$5.24S$	K_2S_2	0.33	0.33
=	CO_2	9.12	9.23
	CO	2.04	2.04
	N_2	8.0	7.55

a striking confirmation of theory is thus presented.

The analysis of the products of explosion of rifle powder carried out by Karolyi is contaminated by a considerable error. He finds,

correctly, no oxygen in the by-products; but no less than 4 atoms or $\frac{1}{16}$th more oxygen appears in the chief products than in the decomposed saltpetre, and if from this the oxygen of the charcoal be subtracted there remain still 1.66 atoms of oxygen more than were contained in the entire powder. If these errors of experiment are corrected, by means of equation (VII), a very good agreement of the numbers calculated according to equation (VIII), and those derived from experiment, is obtained for rifle powder.

The mean composition of the powders of Waltham Abbey is expressed by the symbols

$$16KNO_3+21.18C+6.63S$$

and because, during their combustion, 0.67 mol. of sulphuretted hydrogen is formed, there remain

$$16KNO_3+21.18C+5.96S$$

for the formation of the principal products.

But as the portion of the sulphur which has united with the iron of the apparatus has not been determined by direct experiment, we are obliged to form an estimate of its amount from other considerations.

According to the remarks on pages 37–39, potassium disulphide is produced by the metamorphosis of gunpowder. The combustion of a quantity of powder containing 16 mols. of saltpetre produces, if we take the mean of all the experiments of Noble and Abel, 0.90 mol. of K_2SO_4 and 2.1 mols of K_2S_2, for which quantities 1 mol. of K_2SO_4 and 2 mols of K_2S_2 have been placed in equation (II). From this it follows that 5 atoms of sulphur have taken part in the metamorphosis, and that 0.96 atom of sulphur has remained free or has united with the iron of the explosion apparatus.

The experiments of Karolyi support this conclusion. The Austrian cannon powder containing 8.7 atoms, and the rifle powder 5.66 atoms of sulphur for every 16 mols. of saltpetre, and in the principal products of combustion of the former 5.25 atoms, and in those of the latter 4.89 atoms of this element were found, the rest of the sulphur having remained free. In spite of the great difference of the amounts of sulphur in the two descriptions of powders, we find in their products of combustion, for 16 mols. of decomposed saltpetre, almost the same quantity of sulphur, 5 atoms, in both cases. In Noble and Abel's experiments the sum of the sulphur in the sulphate and disulphide is likewise equal to 5 atoms. From this equality

we may conclude that in Noble and Abel's, as in Karolyi's experiments, during the first stage of combustion, or the stage of explosion, the powders were transformed according to equation (IV), page 33, and that 5 of the 5.96 atoms of sulphur entered into combination. The remaining 0.96S should, during the second stage, have reacted with potassic carbonate according to equation (V), page 40, but as this reaction appears not to have occurred, we may conclude, with great probability, that the 0.96 atom of sulphur united with the metal of the apparatus.

Since in Noble and Abel's experiments all the powder introduced into their apparatus was completely burnt, and as the sum of the weights of the secondary products, after deducting the sulphuretted hydrogen is very small, and finally, because potassium, oxygen and carbon in the principal products of combustion occur almost in the same proportions as in the saltpetre and charcoal of the original powder, we can substitute for x and y, in equation (VIII), the values derived directly from the composition of the powder.

If then we put in equation (VIII) $x = 16$, $y = 21.18$, $z = 5$, and for a, the carbonic oxide, the number 3.23, found by experiment, we obtain for the principal products values which in the following table have been placed by the side of those found by experiment:

$$\left.\begin{matrix} 16KNO_3 \\ +21.18C \\ +5S \end{matrix}\right\} = \left\{\begin{matrix} K_2CO_3 \\ K_2SO_4 \\ K_2S_2 \\ CO_2 \\ CO \\ N_2 \end{matrix}\right.$$

	Theory.	Experiment.
K_2CO_3	5.01	4.98
K_2SO_4	0.96	0.90
K_2S_2	2.01	2.10
CO_2	12.93	13.13
CO	3.23	3.23
N_2	8.00	8.67

The theoretical numbers agree in a very satisfactory manner with those found by experiment.

According to what has been stated in these pages, we conceive the metamorphosis of gunpowder to take place in a shell, or in the bore of a gun, in the following manner. In the first moments after ignition, during the explosion, powders of different composition burn according to the equation

$$16KNO_3 + 13C + 5S = 3K_2CO_3 + 5K_2SO_4 + 9CO_2 + CO + 8N_2$$

and in case of a shell which will burst almost immediately and its contents be scattered about, no further changes take place.

In the bore of a gun the gases expand, move the shot, and by the performance of this work lose a portion of their energy; the products

of the first stage of the metamorphosis, potassic carbonate and potassic sulphate, remain at a red heat, in a fluid condition, for a longer time in contact with free carbon and sulphur, and produce, according to equations (V) and (VI), an additional quantity of carbonic acid. This carbonic acid, which is generated during the movement of the shot in the bore, prevents the too rapid diminution of the tension of the gases; the heat of the solid products is, in part, transformed into *vis viva* of the gas molecules. If the gun were long enough and the quantities of carbon and sulphur not too large, every atom of the former might be oxidized by the oxygen of the potassic sulphate, and the entire amount of the sulphur be converted into potassic disulphide and sulphate by contact with potassic carbonate. But in reality this second stage of the metamorphosis is perhaps never complete; the shot will have left the gun before the termination of these comparatively slow reactions.

The mining powders, strictly considered, do not belong to the category of gunpowders; they contain a large excess of carbon and sulphur. But as their metamorphosis clearly shows the source of the by-products of the combustion of gunpowder, we will discuss here the analytical data furnished by Noble and Abel of an experiment with a sample obtained from Curtis and Harvey.

Composition of the Powder.

	Saltpetre,	61.66
	Sulphur,	15.05
Charcoal	Carbon,	17.93
	Hydrogen,	0.66
	Oxygen,	2.23
	Water,	1.66
		99.19

which may be represented by the symbols:

$$16KNO_3 + 12.3S + \underbrace{39.18C + 16.16H + 3.65O}_{\text{Charcoal.}}$$

This mixture contains sulphur and carbon nearly in the same proportions as they occur in the service powder of Waltham Abbey [S : C = 1 : 3.21], and therefore differs by containing much less saltpetre.

The products of combustion, calculated for 16 mols. of decomposed saltpetre, yielded the following results:

$$\begin{array}{l} 3.66K_2CO_3 + 13.47CO_2 + 2.96H_2S + 2C \\ + 0.04K_2SO_4 + 14.10CO + 1.11CH_4 + 1.27S \\ + 4.11K_2S_2 + 7.96N_2 + 2.2H_2 \\ + 0.36KCNS \qquad\qquad + 0.08[NH_4]_4H_2(CO_3)_3 \end{array}$$

from which we calculate the composition of the powder as follows:

$$16KNO_3 + 12.85S + \underbrace{34.94C + 16.2H + 4.42O}_{\text{Charcoal.}}$$

If we contrast the above results with those obtained by the explosion of the service powders of Waltham Abbey, (I), p. 23, it is seen that the large excess of carbon and sulphur in the mining powder has not diminished the amount of carbonic acid, but greatly increased the quantity of carbonic oxide. In the service powders, the oxygen of the charcoal is eliminated, with hydrogen, as water; in the mining powder it is found at the end of the combustion in union with carbon as carbonic oxide. The hydrogen of the charcoal thus set free partly remains so, partly unites with carbon and nitrogen respectively, forming marsh gas and ammonia, and during the cooling of the products, at a lower temperature, gives rise to the generation of much sulphuretted hydrogen.

In consequence of the great excess of charcoal and sulphur, carbonic oxide, marsh gas and sulphuretted hydrogen are, calculated for 16 mols. of decomposed saltpetre, from four to five times greater in the products of the mining powder than in those of the service powder. The gases of the former are combustible, those of the latter are not.

The potassic sulphocyanate has been formed by the metamorphosis of Curtis and Harvey's powder in quantities ten times as large as were observed amongst the products of the Waltham Abbey mixtures. It is well known that potassic carbonate, sulphur and charcoal, at a white heat, in an atmosphere containing nitrogen, will produce potassic sulphocyanate. The amount of potassic sulphate, as might be expected, present among the products of the mining powder is almost *nil*, and the source of the by-products, of the combustion of gunpowder is laid bare.

If we discard the by-products, we obtain for the combustion of a powder with an excess of carbon the equation:

$$16KNO_3 + 28C + 8S = 4K_2CO_3 + 4K_2S_2 + 12CO_2 + 12CO + 8N_2$$

or more simply:

$$4KNO_3 + 7C + 2S = K_2CO_3 + K_2S_2 + 3CO_2 + 3CO + 2N_2$$

which represents with sufficient exactness the reactions between saltpetre, carbon, and sulphur, when an excess of carbon is present and is introduced in the form of charcoal. Carbonic acid and oxide have been found by experiment to be a little higher, in consequence of the action of the oxygen of the charcoal, potassic carbonate a little lower, in consequence of the formation of some potassic sulphocyanate, than is required by the foregoing equation.

It is also worthy of notice that in spite of the presence of free carbon, more than 13 mols. of CO_2 have remained undecomposed.

From the remarks of the preceding pages it follows that during the complete metamorphosis of powder, the reactions between the constituents of saltpetre, the carbon of the charcoal, and sulphur, take place according to equations (III), (IV), (V), (VI), and (VII), and that by means of equation (VIII) the products, namely, potassic carbonate, potassic sulphate, potassic disulphide, carbonic acid and nitrogen, which are formed during the combustion of a weight of powder containing x mols of saltpetre, y atoms of carbon, and z atoms of sulphur, can be calculated in a satisfactory manner. It now remains to calculate, by means of the same equation, the quantities of heat, gas, and energy which powders of various composition are able to produce.

For this purpose we assume that we have to deal with mixtures of saltpetre, sulphur, and pure *carbon*, and that the combustion is complete, viz. that it runs to the end of the second stage. If we conceive that during the transformation of the powder no carbonic oxide is formed, we should, as a consequence, have a considerable simplification of equation (VIII) without influencing much the calculated amounts of gas and heat.

The conversion of the carbonic oxide to carbonic acid could only take place at the expense of the oxygen in the potassic sulphate; if it occurred according to the equation

$$K_2SO_4 + 4CO = K_2S + 4CO_2$$

the volume of the gas would not be changed. But since potassic disulphide is formed, we have to base our calculations on equation

$$2K_2SO_4 + 7CO = K_2CO_3 + K_2S_2 + 6CO_2$$

from which it follows that, if no carbonic oxide but only carbonic acid is produced, the volume of the entire gas will be diminished by $\frac{1}{7}$th of the volume of the carbonic oxide which in reality is formed.

The greatest amount of carbon in gunpowders generally, as far as I know, is contained in the mixtures of Waltham Abbey, and these also produce the largest quantity of carbonic oxide, 3 mols. or 6 vols. for every 16 mols. of decomposed saltpetre. In addition to 3 mols. of carbonic oxide, 13 mols. of carbonic acid and 8 mols. of nitrogen are generated, which together amount to 24 mols. or 48 vols. of gas.

Now, if in place of carbonic oxide, carbonic acid had been formed, the volume of the entire gas would have been 47.14 instead of 48 vols. In other words, if we frame our calculation on the assumption that only carbonic acid and no oxide has resulted from the combustion, we shall find for the English service powders 1.8 per cent. less gas than was actually obtained by experiment. And as other descriptions of powder contain less carbon than those of Waltham Abbey, in their case the error will be smaller than 1.8 per cent. If then we calculate the volumes of gas which mixtures of saltpetre, carbon, and sulphur in various proportions will produce, on the assumption that no carbonic oxide, but only carbonic acid is formed, we shall obtain numbers that will not differ much from the sum of the volumes of carbonic acid, carbonic oxide, and nitrogen produced by gunpowders containing corresponding quantities of saltpetre, carbon, and sulphur.

By adding the coefficients of carbonic acid and nitrogen of equation (VIII), and putting $x = 16$, and $a = 0$, we obtain for the sum, G, of the molecules of carbonic acid and nitrogen, which a mixture of 16 mols. of saltpetre, y atoms of carbon, and z atoms of sulphur, by its complete combustion, can produce, the equation

$$G = \frac{160 + 20y + 16z}{28}$$

and for the volume, V

$$V = \frac{160 + 20y + 16z}{14} \quad \ldots\ldots\ldots \quad (IX)$$

In Bunsen and Schischkoff's experiment 16 mols. of saltpetre, 13.3 atoms of carbon, and 6.3 atoms of sulphur were consumed in the

formation of the chief products of combustion (page 42). The values $y=13.3$, $z=6.3$, placed in equation (IX), give $V=37.62$. Now 16 mols. of saltpetre, 13.13 atoms of carbon, and 6.3 atoms of sulphur correspond to 1977.2 parts by weight, and if these parts are expressed in grams, then 1 vol. of gas will be equal to 11.19 litres, and 37.62 vols. = 420967.8 cub. centims. Hence, 1 gram of the powder would produce 212.9 cub. centims. of gas.

But only 92.8 per cent. of the powder was transformed, according to equation (VIII), therefore

$$\frac{212.9 \times 92.8}{100} = 197.5 \text{ cub. centims.}$$

Bunsen and Schischkoff found 193.1 cub. centims. If we deduct from this number 4.5 cub. centims. the volume of the gaseous by-products, hydrogen, sulphuretted hydrogen, and oxygen, and add 7.4 cub. centims. for the carbonic acid of the ammonic carbonate, we obtain 196 cub. centims. for the gas found by experiment.

Hence:

Experiment.	Theory.
196 cub. centims.	197.5 cub. centims.

The chief products of the combustion of Linck's powder contain according to his analysis, the powder constituents in the proportion

$$16KNO_3 + 15.06C + 7.44S.$$

If we substitute in equation (IX) for y the number 15, and for z 7.5, we obtain $V=41.42$. $16KNO_3 + 15C + 7.5S$ corresponds to 2036 parts by weight. Expressed in grams 1 vol. of the gas will be equal to 11190 cub. centims., therefore 41.42 vols. = 463489.8 cub. centims., and 1 gram of the powder would yield 227.6 cub. centims.

As only 91.7 per cent. of the Würtemberg service powder was transformed, according to equation (VIII), we have

$$\frac{227.6 \times 91.7}{100} = 208.7 \text{ cub. centims. for the theoretical volume.}$$

Linck found 218.35 cub. centims.; but from this must be subtracted 15.67 cub. centims. for sulphuretted hydrogen, 3.56 cub. centims. for hydrogen, and 0.09 for oxygen, leaving 199.3 cub. centims. of gas as the product of combustion of 1 gram of powder

according to equation (VIII). Adding 5.8 cub. centims. for carbonic acid in ammonic carbonate, we obtain

Experiment.	Theory.
205.1 cub. centims.	208.7 cub. centims.

If the difficulties which have to be overcome in order to obtain exact results in the determination of the products of explosion of gunpowder are considered, the differences between the theoretical and experimental numbers appear to come within the errors of observation.

In Noble and Abel's experiments 16 mols. of saltpetre, 21.35 atoms of carbon, and 5.1 atoms of sulphur were transformed according to equation (VIII). If in equation (IX) for y the number 21.35, and for z the number 5.1 is substituted, the volume of gas is found to be 47.73.

$16KNO_3 + 21.35C + 5.1S$ are equal to 2035.4 parts by weight, and 47.73 vols. = 534098.7 cub. centims., if the weight is expressed in grams, therefore 1 gram of the powder yields 262.4 cub. centims. of gas.

On an average, 93.75 per cent. of the weight of the powder was transformed, according to equation (VIII), hence we have:

$$\frac{262.4 \times 93.75}{100} = 246.0 \text{ cub. centims.}$$

for the theoretical volume of gas formed by the combustion of 1 gram of powder. The mean of Noble and Abel's observations is 268.7 cub. centims. From this number 14.5 cub. centims. must be subtracted for the volumes of sulphuretted hydrogen, marsh gas, and hydrogen, leaving 254.2 cub. centims. for the carbonic acid, carbonic oxide, and nitrogen. Therefore we obtain, for the volume of the gas produced by 1 gram of service powder from Waltham Abbey,

Experiment.	Theory.
254.2 cub. centims.	246 cub. centims.

the difference between the two numbers is only 1.9 cub. centim. greater than the greatest difference between two observations made with R. L. G. powder.

The three descriptions of powder, Bunsen and Schischkoff's, Linck's, and Noble and Abel's, contain from 13 to 21 atoms of carbon, and

from 6.3 to 8.4 atoms of sulphur for every 16 mols. of saltpetre, and are good representatives of gunpowder in general.

The values calculated for the volumes of the gases furnished by these powders are near enough to those found by experiment to show the correctness of the theoretical considerations on which equation (IX) has been framed, and to justify the use of this equation for the determination of the volume of gas produced by mixtures which contain saltpetre, carbon, and sulphur in proportions different from those of the Waltham Abbey, the Würtemburg, or Bunsen and Schischkoff's powder.

The amount of heat generated by the combustion of a mixture of saltpetre, *pure* carbon, and sulphur can be found in the following manner:

If we assume, as in the case of the calculation of the gas, that no carbonic oxide is formed, that is to say put $a=0$, multiply the heat of formation of each product with its coefficient in equation (VIII), add the products thus formed and subtract from the sum the heat of formation of saltpetre: the difference will be equal to the heat generated by the combustion of the mixture.

Heat of formation of 1 mol.			$K_2CO_3=279530$*
"	"	"	$K_2SO_4=344640$†
"	"	"	$K_2S_2=108000$‡
"	"	"	$CO_2=97000$§
"	"	"	$KNO_3=119480$‖

Hence we obtain for the heat of combustion, W

$$[\tfrac{4}{21}x+\tfrac{5}{21}y-\tfrac{1}{21}z]279530+[\tfrac{20}{21}x-\tfrac{1}{21}y+\tfrac{4}{21}z]344640$$
$$+[-\tfrac{10}{21}x+\tfrac{5}{21}y+\tfrac{13}{21}z]108000+[-\tfrac{4}{21}x+\tfrac{20}{21}y+\tfrac{1}{21}z]97000$$
$$-x\times 119480=W\text{; or if } x=16,$$
$$W=1000[1827.154-16.925y-8.788z] \quad . \quad . \quad . \quad . \quad . \quad (X)$$

* J. Thomsen, Berichte der deutschen chemischen Gesellschaft in Berlin, Bd. xii, p. 2031.

† *Ibid.*, p. 2032; Bd. xiii, p. 961.

‡ Sabatier, Comptes Rendus, tom. xc., 1557–1560; Chem. Soc. Journal, 1880, p. 689.

§ J. Thomsen, Berichte der deutschen chemischen Gesellschaft in Berlin, Bd. xiii, p. 1329.

‖ *Ibid.*, p. 500.

That is to say, a mixture of 16 mols. of saltpetre, y atoms of carbon, and z atoms of sulphur, will, by its complete transformation according to equation (VIII), produce W units of heat.

An error attaches to W in consequence of the assumed non-formation of carbonic oxide.

The quantity of this substance produced by the Waltham Abbey powders is greater than that formed by other mixtures, but as the error attaching to W in the case of the English service powders does not amount to more than 2.6 per cent. of the total heat, an error smaller than the usual errors of observation, it may be neglected for the sake of the great simplification of the formula.

It is perhaps desirable again to call attention to the condition that the equations (IX) and (X) apply only to mixtures which contain their constituents in such proportions that they can completely transform themselves according to equation (VIII). Mining powders are excluded.

The charcoal of gunpowder is, however, not pure carbon, but contains also hydrogen, oxygen and water.

The high temperature generated by the explosion causes probably the dissociation of these elements, and if, as in Noble and Abel's experiments, all the carbon is oxidized at the expense of the oxygen of the saltpetre, the oxygen of the charcoal will reunite with hydrogen and form water.

The heat absorbed by the decomposition of the charcoal is not known. A portion of the hydrogen unites with nitrogen, carbon, and sulphur respectively, forming ammonia, marsh gas, and sulphuretted hydrogen. The total heat which is either liberated or absorbed by all these secondary reactions, appears, however, to be a small quantity, when compared with the amount given off by the formation of potassic carbonate, potassic sulphate, potassic disulphide, and carbonic acid. The following condition has a greater influence on the heat of combustion of ordinary gunpowder.

The combustion ought to be complete; but in Bunsen and Schischkoff's as well as in Linck's experiments, a not inconsiderable portion of the powder remained unburnt. In every calorimetric determination all the products ought to be carefully examined, and this it seems was not done by those who have determined the heat of combustion of gunpowder. From the foregoing remarks we conclude that no close agreement can be expected between the heat of combustion calculated by means of equation (X) for a mixture of 16 mols. of

KNO_3, y atoms of C, and z atoms of S, and that generated by an ordinary gunpowder containing saltpetre, carbon, and sulphur in the same proportions.

In Bunsen and Schischkoff's powder we have for every 16 mols. of saltpetre, 13.3 atoms of C, and 6.3 atoms of S. If we substitute for y the number 13.3 and for z the number 6.3 in equation (X), we obtain:

$$W = 1546688 \text{ cal.}$$

$16KNO_3 + 13.3C + 6.3S = 1977.2$ parts by weight, or one part of their powder would furnish 782 units of heat. Bunsen and Schischkoff found 619.5. This number is, I believe, the result of one experiment made with 0.71 gram of powder; it is evidently much too small. Noble and Abel found, for the heat of combustion of the powders of Waltham Abbey, values which vary between 696 and 727 units. Their numerous calorimetric determinations were made by the combustion of the powders in the explosion apparatus, and several hundred grams were used in each experiment. It is known that the combustion under such conditions is complete. But as the English powders contain much more carbon than Bunsen and Schischkoff's, or 4 per cent. less of saltpetre, they ought to have produced less heat. From these considerations it seems to follow that in Bunsen and Schischkoff's experiment a portion of the powder taken escaped combustion.

It has been shown that 16 mols. of saltpetre, 21 atoms of C, and 5 atoms of S take part in the metamorphosis of the powders of Waltham Abbey. If for y the number 21, for z the number 5, are substituted in equation (X), the value of W is found to be equal to 1427789 cal.; but $16KNO_3 + 21C + 5S = 2028$ parts by weight, hence 1 gram of powder would generate 704 units of heat.

Noble and Abel found in the first series, comprising five experiments, numbers which give a mean of 702.34 units for 1 gram of powder.

In another series of 19 experiments greater numbers were obtained than in the first. The mean of all 24 experiments is equal to 719.9 cal.

The theoretical number of 704 cal., however, corresponds to a mixture of saltpetre, sulphur, and pure carbon.

93.75 per cent. of the English service powders are transformed, according to equation (VIII), hence the calculated heat generated by

the reactions between saltpetre, sulphur, and pure carbon of 1 gram of English service powder is:

$$\frac{704 \times 93.75}{100} = 660 \text{ cal.}$$

This theoretical quantity is 59.9 units, or 8.4 per cent. less than the amount found by experiment, a difference which would be much smaller if the amount of heat produced by the action of the sulphur upon the iron of the apparatus were known and could be subtracted from the experimental number. It is worthy of notice that the differences in the amounts of heat found in several experiments made with the same description of powder are nearly as great as the differences between the calculated and observed results.

A sample of powder manufactured by Curtis and Harvey, and marked No. 6, gave in four experiments

I.	II.	III.	IV.
732.9	744.9	755.7	784

units of heat, hence, between the first and last experiment a difference of 51.1 units.

Another heat determination may be here introduced. $16KNO_3 + 16.4C + 5.5S$ of the Spanish pebble powder burnt according to the reactions on which equation (VIII) is based, 16.4 for y, and 5.5 for z put in equation (X), make $W = 1501250$ cal.

As

$$16KNO_3 + 16.4C + 5.5S$$

are equal to 1988.8 parts by weight, 1 gram of the powder generates 754 cal.

If 5 per cent. are deducted for hydrogen, oxygen, and ash, we obtain:

$$\frac{754 \times 95}{100} = 716.3 \text{ cal.}$$

for the calculated heat of 1 gram of powder. Experiment gave 762.3, or 46 units more.

It follows as a general result from these considerations that the mean quantities of heat generated by the combustion of the English service and Spanish pebble powders are about 60 units greater than the theoretical values. If, however, the amount of heat generated by the action of the sulphur upon the iron of the explosion apparatus

were known, and could be subtracted from the observed quantities of heat, the difference would become much smaller.

On the other hand, the theoretical numbers stand to each other nearly in the same ratios as do the corresponding experimental values.

The equations (VIII), (IX), and (X) will now be used to determine the composition of an ideal powder, that is to say, of a powder composed of saltpetre, *pure* carbon, and sulphur, which shall, of all possible mixtures of this nature, possess the greatest energy; the results so obtained will be nearly correct for ordinary gunpowders. This would be the most general form of the problem of the explosion of gunpowder which could be proposed for solution to a chemist.

Equations (IX) and (X), viz:

$$V = +\tfrac{160}{14} + \tfrac{20}{11}y + \tfrac{16}{11}z \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (IX)$$

$$W = 1000[1827.154 - 16.925y - 8.788z] \quad . \quad . \quad . \quad (X)$$

at once show that, if for a given weight of saltpetre, 16 mols., the carbon and sulphur of the mixture were allowed to increase, the volume of gas generated by combustion would likewise increase, but the quantity of heat will grow smaller, and if the carbon and sulphur be diminished the gas will also become less, but the heat of combustion will increase.

Noble and Abel have called attention to the fact * that the products of heat and gas obtained by them in their various experiments with different descriptions of powder do not differ much from each other. The explanation of this interesting observation is to be found in equations (IX) and (X).

The work which can be performed by a given weight of powder will *cæteris paribus*, be proportional to the volume of gas and amount of heat, respectively, which the powder can produce by its combustion, and, hence, will be proportional to the product of both. This is, however, only approximately correct, because, if we have to compare the work which two powders of different composition can produce, the gases given off by the one will not contain the elements in the same proportion as those produced by the other; a portion of the energy developed will be consumed in the performance of interior work during the expansion of the carbonic acid. This portion is, however, very small.

* Phil. Trans., 1880, p. 230.

The product of (IX) and (X) is:

$$10440.88 - 12.09y^2 + 1208.39y - 15.95yz + 993.867z - 5.022z^2 =$$

$$\frac{W.V}{1000 \times 2} = E \quad . \quad . \quad . \quad . \quad . \quad . \quad (XI)$$

the factor 1000 in (X) has been omitted, or W divided by 1000, and V by division by 2 has been converted from volumes into molecules.

The equations (IX) and (X) are based on the assumption that no carbonic oxide is formed during the combustion of a mixture of saltpetre, carbon, and sulphur. In consequence, the volume of gas calculated by formula (IX) for a mixture of the composition like those of Waltham Abbey is 1.8 per cent. smaller, and the amount of heat according to equation (X) 2.6 per cent. larger than it would have been if the carbonic oxide had been taken into consideration. These errors nearly compensate each other in the product E in the equation (XI), so that the values of E are but *little* affected by putting a, the carbonic oxide, $= 0$ in equation (VIII).

Equation (XI) can be used for the calculation of the relative energies of weights of powder containing 16 mols. of saltpetre, y atoms of carbon, and z atoms of sulphur.

The question now arises for what values of y and z will E in equation (XI) assume a maximum value, provided that y and z render the coefficients of equation (VIII) positive,—the condition which must be fulfilled in a chemical equation.

If we put $a = 0$ in equation (VIII), we obtain:

$$\left.\begin{matrix} x\mathrm{KNO_3} \\ +y\mathrm{C} \\ +z\mathrm{S} \end{matrix}\right\} = \left\{\begin{matrix} \frac{1}{28}[\quad 4x + 8y - 16z](\mathrm{K_2CO_3}) \\ +\frac{1}{28}[\quad 20x - 16y + 4z](\mathrm{K_2SO_4}) \\ +\frac{1}{28}[-10x + 8y + 12z](\mathrm{K_2S_2}) \\ +\frac{1}{28}[-4x + 20y + 16z](\mathrm{CO_2}) \\ +\frac{1}{2}x\mathrm{N_2} \end{matrix}\right. \quad . \quad . \quad . \quad (XII)$$

in which, as in (VIII), x, y, and z denote positive numbers. Let a rectangular coordinate system be given with its origin in point A, and the coordinates of a point P be represented by x, y, and z. The coefficients of potassic carbonate, sulphate, and disulphide in (XII) will for certain values of x, y, and z be equal to 0. The equations:

$$\begin{aligned} 4x + 8y - 16z &= 0 \\ 20x - 16y + 4z &= 0 \\ -10x + 8y + 12z &= 0 \end{aligned}$$

satisfied by these values represent three planes which form a trihedral angle with its vertex in the origin and one edge in the x A y plane. The points within the trihedral angle have coordinates which will render all the coefficients of (XII) positive, those situated outside give values for x, y, and z, which will make at least one of the three coefficients of the potassium salts negative. Hence, coordinates of the points within the trihedral angle denote quantities of saltpetre, carbon, and sulphur which can transform themselves completely into potassic carbonate, sulphate, disulphide, carbonic acid, and nitrogen, whereas the points outside represent, by their coordinates, quantities of the powder constituents which cannot do so entirely, because one or the other of these constituents is in excess or defect.

The points on the faces of the trihedral angle correspond to mixtures which will burn with the production of two, those on the edges with only one, of the three potassium salts.

But to show the connection between the quantities of the constituents of a given powder and those of its products of combustion, we need only consider relative, and not absolute quantities.

If a straight line be drawn through the origin within the trihedral angle, the ratios of the coordinates of every point upon it will be the same.

A plane at right angles to the x axis will cut the faces of the trihedral angle so as to form a triangle B D C (see Fig. 1), and the coordinates of the points inside this triangle will represent all possible proportions of carbon and sulphur which can with a given weight of saltpetre transform themselves into the products of combustion indicated in equation (XII). If then in (XII) we attribute to x the constant value 16, we obtain:

$$\left.\begin{matrix} 16KNO_3 \\ +yC \\ +zS \end{matrix}\right\} = \left\{\begin{matrix} \frac{1}{32}[\ \ 64 + 8y - 16z](K_2CO_3) \\ +\frac{1}{32}[\ 320 - 16y + 4z](K_2SO_4) \\ +\frac{1}{32}[-160 + 8y + 12z](K_2S_2) \\ +\frac{1}{32}[-\ 64 + 20y + 16z](CO_2) \\ +8N_2 \end{matrix}\right. \quad . \; . \quad \text{(XIII)}$$

and from it the equations:

$$64 + 8y - 16z = 0 \quad . \; . \; . \; . \; . \quad \text{(XIV)}$$

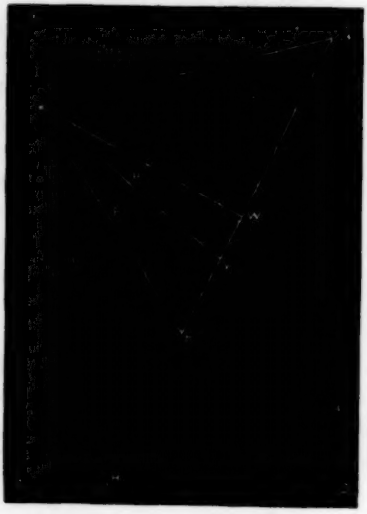
$$320 - 16y + 4z = 0 \quad . \; . \; . \; . \; . \quad \text{(XV)}$$

$$-160 + 8y + 12z = 0 \quad . \; . \; . \; . \; . \quad \text{(XVI)}$$

of the lines of intersection of the plane at right angles to the x axis

with the faces of the trihedral angle, in other words, the sides of the triangle B D C (Fig. 1).

Fig. 1.



It will be observed that

(XIV) is the equation of B C
(XV) " " D C
(XVI) " " B D.

The points of the side B C represent, by their coordinates, mixtures of carbon and sulphur with 16 mols. of saltpetre, which will by complete combustion produce no potassic carbonate; those of side D C such as will not form potassic sulphate, and finally, the coordinates of the points of side B D denote quantities of carbon and sulphur which will burn with 16 mols. of saltpetre without the formation of potassic disulphide. The coefficient of carbonic acid will never vanish, but be always positive, because if it is equated to zero it will represent the line G H in figure, which does not intersect the triangle B D C.

All points outside the triangle B D C have coordinates which render at least one of the three coefficients of the potassium salts in equation (XIII) negative, and consequently have reference to mixtures of carbon and sulphur with 16 mols. of saltpetre, which contain either too much or too little of one or both of the two elements named.

The coordinates of the line B D represent mixtures of carbon and sulphur with 16 mols. of saltpetre, which will burn without the formation of potassic disulphide, and those of the line B C, such as will not produce potassic carbonate; hence, it may be concluded that the coordinates of B, the point of intersection of the two lines, will correspond to a powder which will be transformed without formation of potassic carbonate and disulphide, and will only yield, as products of its combustion, potassic sulphate, carbonic acid, and nitrogen. The coordinates of point B are:

$$y = 8$$
$$z = 8$$

and these values substituted in equation (XIII),

$$16KNO_3 + 8C + 8S = 8K_2SO_4 + 8CO_2 + 8N_2$$

or simplified:

$$2KNO_3 + C + S = K_2SO_4 + CO_2 + N_2$$

Accordingly a mixture of 82.1 parts of saltpetre, 4.8 parts pure carbon, and 13 parts of sulphur may be expected to produce during complete combustion only potassic sulphate, carbonic acid, and nitrogen, and this conclusion is in perfect accord with the thermochemical relations of the reacting substances and with experimental results. And by a similar method of reasoning we arrive at the conclusion that the coordinates of the point D represent a mixture which will burn according to the equation:

$$16KNO_3 + 20C = 8K_2CO_3 + 12CO_2 + 8N_2$$

or simplified:

$$4KNO_3 + 5C = 2K_2CO_3 + 3CO_2 + 2N_2$$

and those of point C according to

$$16KNO_3 + 24C + 16S = 8K_2S_2 + 24CO_2 + 8N_2$$

or simplified:

$$2KNO_3 + 3C + 2S = K_2S_2 + 3CO_2 + N_2$$

if in this last equation the potassic disulphide be changed into monosulphide, then the equation would become identical with the old one, which for many years was supposed to represent the metamorphosis of all sorts of gunpowders.

As already observed, all points within the triangle represent, by their coordinates, mixtures of carbon and sulphur with 16 mols. of

KNO_3, which besides carbonic acid and nitrogen, will yield during their combustion three potassium salts.

The geometrical construction of the coefficients of equation (XIII) does not only offer the advantage of representing by the coordinates of the points within the triangle B D C all possible proportions of saltpetre, carbon, and sulphur which can transform themselves into potassic carbonate, potassic sulphate, potassic disulphide, carbonic acid and nitrogen, but it also enables us to deduce at once, geometrically, the quantities of these products of combustion.

If we desire to know the composition of all these mixtures which contain variable quantities of carbon and sulphur, but shall all produce by their combustion the same amount of potassic carbonate, we can deduce the answer from the following considerations:

For such mixtures the coefficient of the potassic carbonate in equation (XIII) must assume a constant value. Hence,

$$64 + 8y - 16z = c$$

and

$$y = 2z + \frac{c - 64}{8}$$

the equation of a line parallel to the side B C of the triangle. The coordinates of the points of such a line indicate the composition of mixtures which will burn with production of the same amount of potassic carbonate. The amount of potassic carbonate is constant for each parallel line, but changes from one line to another. Now as they intersect the lines B D and D C, it is only necessary to ascertain the amounts of potassic carbonate corresponding to the points of one of these sides in order to know the amount of potassic carbonate formed by the combustion of a mixture represented by the coordinates of any point within the triangle.

Similar considerations lead to the equation:

$$y = \tfrac{1}{4}z + \frac{320 - c}{16}$$

for mixtures which will burn with production of equal quantities of potassic sulphate.

This is the equation of a line parallel to the side D C. All these parallel lines intersect the line D B. If, then, we know the quantity of potassic sulphate corresponding to each point of D B, we shall likewise know the amount of this salt which any mixture, the composition of which is represented by the coordinates of one of the points

of the triangle, can produce by its combustion. Now the powders, the composition of which is given by the coordinates of the points of B D, produce by their combustion an amount of potassic sulphate which in molecules is directly expressed by the length of the corresponding abscissæ of the points.

Since x has been taken constant $= 16$, the sum of the molecules of the potassium salts must always be $= 8$, and as the points of the line B D represent only mixtures which burn with the production of two of these salts, potassic carbonate and sulphate, it is only necessary in order to know the respective quantities of each of these salts for a point F on B D, to subtract the value of the abscissa of F from 8 to obtain the molecules of potassic carbonate which would be produced by the combustion of a mixture the composition of which is given by the coordinates of F.

The coefficient of potassic disulphide in equation (XIII) is $= -160+8y+12z$, from which we deduce the equation:

$$y = -\tfrac{3}{2}z + \frac{c+160}{8}$$

which is the equation of a line parallel to side B D. The points of such a line represent by their coordinates mixtures which will burn with the production of the same amount of potassic disulphide, which amount is constant for the same line, but changes from one to another. This amount is found for a mixture represented by the coordinates of a point P, if through P a line is drawn parallel to B D, and the abscissa of the point of intersection with the side D C is ascertained; half the length of this abscissa represents the number of molecules of potassic disulphide formed by the combustion of the mixture represented by point P.

For mixtures which are to burn with the evolution of the same quantity of carbonic acid we have:

$$-64+20y+16z = c$$

or

$$y = -\tfrac{4}{5}z + \frac{c+64}{20}$$

an equation which represents a line parallel to G H, on which for two points y, z and y', z', five times the difference of the ordinates is equal to four times the difference of the abscissæ.

The line D V in our figure is parallel to G H. In order to find the amount of carbonic acid which is developed by the combustion of a mixture the composition of which is represented by the coordinates

of a point P, we have to draw through P a line parallel to D V or G H, and determine the length of the ordinate of the point of intersection with the side B C; this length is equal to the number of molecules of carbonic acid, because for all mixtures represented by the points of the side B C, the number of molecules of carbonic acid produced is equal to the number of atoms of carbon the mixtures contain.

We will now proceed to determine, by aid of the method just explained, the quantities of the products of combustion of a mixture the composition of which is represented by the coordinates of the point R on D V, $y = 16$, $z = 5$. A line drawn through R parallel to D C intersects D B in the point S; the abscissa of S $= 3$, hence 3 mols. of potassic sulphate are produced.

A line drawn through R parallel to B C, cuts the side D B, in F; the abscissa of F $= 4$; $8 - 4 = 4$; hence we obtain 4 mols. of potassic carbonate.

A line through R parallel to D B, intersects D C, in point U; the abscissa of U $= 2$; $\frac{2}{2} = 1$; hence 1 mol. of potassic disulphide is formed.

R is a point of D V, the ordinate of V, y, $= 12$, hence we have 12 mols. of carbonic acid.

Nitrogen is for all mixtures a constant $= 8N_2$, therefore the equation for the metamorphosis of a mixture, the composition of which is expressed by the coordinates of the point R, is:

$$16KNO_3 + 16C + 5S = 4K_2CO_3 + 3K_2SO_4 + K_2S_2 + 12CO_2 = 8N_2$$

The great advantage of the geometrical construction of the coefficients of equation (XIII) consists in this, that we can at once ascertain by an inspection of figure B C D, the influence of all possible variations of the quantities of carbon and sulphur in given mixtures, upon the proportions of the corresponding products of combustion.

Similar considerations enable us to find the quantities of gas and heat.

If we add the constant 8 for nitrogen to the number of molecules of carbonic acid determined as previously explained, we obtain the total number of gas molecules produced by the combustion of a mixture represented by the coordinates of a given point.

The heat generated is found by equation (X).

For powders which shall produce by their combustion the same amount of heat, we have:

$$1.92y = -z + \frac{1827154 - c}{8788}$$

for which we may adopt without serious error

$$2y = -z + \frac{1827154 - c}{8788} \quad \ldots\ldots \text{(XVII)}$$

This is the equation of a line perpendicular to the side B C. For an appropriate value of C it becomes:

$$2y = -z + 40$$

and then represents the line D W in the figure.

Mixtures, the composition of which can be represented by the points of such a line, will generate by their combustion very nearly the same amount of heat. A powder composed of $16KNO_3 + 20C$ corresponds to the point D, and one consisting of $16KNO_3 + 14.4C + 11.25S$ to the point W. The first generates according to equation (X) 1,488,654, and the second 1,484,569 units of heat, two numbers which differ only by 0.27 per cent., and may therefore be considered identical for practical purposes.

A line drawn through the point R, perpendicular to the side B C, intersects the latter in the point $y = 13.25$, $z = 10.6$; hence two powders composed of

$$16KNO_3 + 16C + 5S$$
$$\text{and } 16KNO_3 + 13.25C + 10.6S$$

will generate by their combustion the same, or more correctly, nearly the same amount of heat.

Consequently, if we know the heat of combustion of all the mixtures represented by the coordinates of the points of the line B C, then we know likewise the heat of combustion of all the mixtures the composition of which is represented by *any* point within the triangle. And we arrive at the same conclusion with regard to the amount of gas which a mixture can produce, the composition of which is represented by any point inside the triangle B C D. According to equation (X) the heat of combustion reaches its maximum when y and z assume their smallest values, and, on the other hand, when y and z are greatest the heat of combustion will be a minimum. Therefore, an inspection of the triangle B D C teaches that of all the infinite number of mix-

tures of saltpetre, carbon, and sulphur which can be transformed according to equation (XIII), the one which is composed of

$$16KNO_3 + 8C + 8S$$

will produce by its combustion the greatest, and the one composed of

$$16KNO_3 + 24C + 16S$$

the smallest quantity of heat: the first is represented by point B, the second by point C of the figure.

Further, it follows from equation (IX) that the first of the above mixtures will form the smallest, and the second the largest quantity of gas.

If then we place ourselves at the point B of line B C, to which corresponds the generation of the greatest quantity of heat and that of the smallest quantity of gas, and move from B towards C, the amounts of heat produced by the mixtures represented by the coordinates of the several points will constantly decrease, and the volumes of gas increase, until the former reach in C their minimum, and the latter their maximum value.

We calculate for B and C

	Volume of gas.	Units of heat.
B	32	1,621,450
C	64	1,280,346

and between these numbers, 32 and 64 for the volume of the gas, and 1,280,346 and 1,621,450 for the units of heat, fluctuate the quantities of heat and gas which any possible mixture of 16 mols. of saltpetre with carbon and sulphur can produce, provided that these constituents, during combustion, transform themselves according to equation (XIII). We will now show that the product, E, of the units of heat and the molecules of gas as given by equation (XI), is greater for mixtures represented by points of line B C than for such as are represented by any other point within the triangle.

If we take, on the line D W, perpendicular to B C, the point $y = 17$, $z = 6$, then the mixture corresponding to this point and the one corresponding to point W will produce the same quantity of heat. The amount of gas generated by the mixture represented by point $y = 17$, $z = 6$, must be less than the quantity produced by the mixture corresponding to point W. Because, if we draw a line through $y = 17$, $z = 6$, parallel to D V, the point of intersection with B C will lie between W and V, but the further the point of intersec-

tion is away from W in the direction towards B the smaller the volumes of gas will be. Hence, the product of gas and heat for $y=17$, $z=6$ must be smaller than the one for point W, and the further we proceed from W towards D the smaller this product must be. But what holds good for the line D W also applies to every other perpendicular which can be drawn to B C.

Therefore the maximum value of the product of gas and heat must be produced by a mixture the composition of which is expressed by the coordinates of one of the points of the line B C.

If we represent the function on the right of the equation (XI) by $F(y, z)$, and the equation of the line B C (XIV) by $\varphi(y, z)=0$, then the differential equation

$$\frac{dF}{dz}\cdot\frac{d\varphi}{dy}-\frac{dF}{dy}\cdot\frac{d\varphi}{dz}=0$$

together with $\varphi(y, z)=0$ give the values of y and z, for which E in equation (XI) becomes a maximum. We find $y=38.02$ and $z=23.0$. Hence, a powder composed of

$$16KNO_3+38C+23S$$

will by its complete combustion produce amounts of heat and gas the product of which will be the required maximum. But a mixture which shall transform itself according to equation (XIII) can only contain per 16 mols. of saltpetre from 8 to 24 atoms of carbon, and from 8 to 16 atoms of sulphur. Hence, the product of the quantities of heat and gas will be a maximum for a powder composed of

$$16KNO_3+24C+16S$$

because according to the coefficients of equation (XI) E will become greater and greater when y increases from 8 to 24, and z from 8 to 16, until it reaches its maximum value at a point $y=38$ and $z=23$, outside the triangle B C D.

For the purpose of calculating the values of E for different mixtures, we may simplify the coefficients and constant of equation (XI), and write accordingly

$$10441-12.1y^2+1208.4y-16yz+994z-5z^2=E \quad . \quad . \quad \text{(XVIII)}$$

E has been calculated by means of this equation for different values of y and z with the following results:

$y = 8$,	$z = 8$,	$E = 25941.8$
$y = 10$,	$z = 9$,	$E = 28416$
$y = 12$,	$z = 10$,	$E = 30719.4$
$y = 14$,	$z = 11$,	$E = 32852$
$y = 16$,	$z = 12$,	$E = 34813.8$
$y = 18$,	$z = 13$,	$E = 36604.8$
$y = 20$,	$z = 14$,	$E = 38225$
$y = 22$,	$z = 15$,	$E = 39674.4$
$y = 24$,	$z = 16$,	$E = 40953.0$

If, therefore, the carbon and the sulphur increase in different mixtures, the carbon by 2 atoms and the sulphur by 1 atom from

$$16KNO_3 + 8C + 8S$$

to

$$16KNO_3 + 24C + 16S$$

then parallel with this change of the carbon and sulphur, a regular increase of the product of heat and gas takes place, until for 24C and 16S it becomes a little more than one and-a-half times as great as for 8C and 8S.

If saltpetre and sulphur remain constant, and the carbon alone changes, then also an increase of the carbon is followed by one of E.

$y = 8$,	$z = 8$,	$E = 25941.8$
$y = 16$,	$z = 8$,	$E = 32261.8$
$y = 18$,	$z = 8$,	$E = 33599.8$
$y = 22$,	$z = 8$,	$E = 35985.8$

The energy of a powder of the composition:

$$16KNO_3 + 22C + 8S$$

is about $\frac{2}{3}$ths greater than that of one containing

$$16KNO_3 + 8C + 8S.$$

If saltpetre and carbon are constant, but the sulphur changes, we obtain the following values for E:

$y = 14$,	$z = 4$,	$E = 27987.0$
$y = 14$,	$z = 11$,	$E = 32852.0$
$y = 16$,	$z = 6$,	$E = 30925.8$
$y = 16$,	$z = 8$,	$E = 32261.8$
$y = 16$,	$z = 12$,	$E = 34813.8$

$y=18$,	$z=8$,	$E=33599.8$
$y=18$,	$z=13$,	$E=36604.8$
$y=20$,	$z=0$,	$E=29769$
$y=20$,	$z=5$,	$E=33014$
$y=20$,	$z=9$,	$E=35430$
$y=20$,	$z=14$,	$E=38225$
$y=22$,	$z=8$,	$E=35985.4$
$y=22$,	$z=15$,	$E=39674.4$

It follows from these examples that for a constant quantity of saltpetre, in varying mixtures of saltpetre, carbon, and sulphur, the relative energy of the mixtures increases with both the carbon and the sulphur, and reaches its maximum for 24 atoms of carbon and 16 atoms of sulphur, the highest amounts of these constituents which can exist in a powder according to equation (XIII).

The difference of E for two mixtures of the same amount of saltpetre, but varying quantities of carbon and sulphur, becomes much smaller with equal weights of such mixtures. If, then, we multiply x, y, and z with their respective molecular or atomic weights, and divide E by the sum of the numbers so obtained, we find the relative energy, say E′, of equal weights of various mixtures.

The following table gives the value of E′ for mixtures which contain 16 mols. of KNO_3, y atoms of C, and z atoms of S.

$y=8$,	$z=8$,	$E'=13.18$
$y=16$,	$z=8$,	$E'=15.63$
$y=18$,	$z=8$,	$E'=16.09$
$y=22$,	$z=8$,	$E'=16.84$
$y=11$,	$z=6$,	$E'=13.91$
$y=13$,	$z=6$,	$E'=14.58$
$y=16$,	$z=6$,	$E'=15.46$
$y=21$,	$z=6$,	$E'=16.62$
$y=11$,	$z=6$,	$E'=13.91$
$y=11$,	$z=9.5$,	$E'=14.41$
$y=14$,	$z=4$,	$E'=14.63$
$y=14$,	$z=8$,	$E'=15.11$
$y=14$,	$z=11$,	$E'=15.38$

$y = 16$,	$z = 2.66$	$E' = 15.11$
$y = 16$,	$z = 6$,	$E' = 15.46$
$y = 16$,	$z = 8$,	$E' = 15.63$
$y = 16$,	$z = 12$,	$E' = 15.88$
$y = 18$,	$z = 8$,	$E' = 16.09$
$y = 18$,	$z = 13$,	$E' = 16.28$
$y = 20$,	$z = 0$,	$E' = 16.03$
$y = 20$,	$z = 5$,	$E' = 16.37$
$y = 20$,	$z = 9$,	$E' = 16.52$
$y = 20$,	$z = 14$,	$E' = 16.59$
$y = 21$,	$z = 4$,	$E' = 16.54$
$y = 21$,	$z = 6$,	$E' = 16.62$
$y = 22$,	$z = 8$,	$E' = 16.84$
$y = 22$,	$z = 15$,	$E' = 16.81$
$y = 24$,	$z = 16$,	$E' = 16.95$

It follows from these numbers that E′ becomes greater when y or z, or both simultaneously, increase, but proportionately less so than is the case with weights of mixtures which contain equal weights of saltpetre, viz. 16 mols.

The smallest value of E′ is 13.18, the highest 16.95; hence the latter is about 28 per cent. greater.

The highest value of E, on the other hand, is more than 50 per cent. greater than the lowest. Further, it is apparent that for mixtures for which y and z assume high values the differences of E′ become very small.

The powder

$$16KNO_3 + 14C + 4S$$

differs from

$$16KNO_3 + 14C + 11S$$

by 7 atoms of sulphur.

The two mixtures

$$16KNO_3 + 22C + 8S$$

and $16KNO_3 + 22C + 15S$

differ by the same amount of sulphur.

The two former show, for E′, the difference 0.75, the latter only 0.03; indeed, many of the various mixtures for which y and z have high values, give, when equal weights are considered, almost the same number for E′.

If we draw a line through the triangle B C D (see Fig. 1), from the point $y = 22$, $z = 8$ to the point $y = 8$, $z = 8$, it will be observed that for mixtures represented by the coordinates of the points on the right-hand side of this line, the value of E′ only increases very little if the sulphur is increased beyond 8 atoms and the carbon kept constant. This circumstance is of great practical importance. The analyses of military and sporting powders known to me, all give for 16 mols. of saltpetre an amount of sulphur which varies between 5.5 and 8.7 atoms. There would be very little, if any, gain in energy if, for 16 mols. of saltpetre, more than about 8 atoms of sulphur were introduced into the powder; especially would this be the case with mixtures in which for 16 mols. of saltpetre more than 16 atoms of carbon are present.

E′ obtains its maximum value, 16.95, when the powder contains:

$$16KNO_3+24C+16S.$$

Such a large amount of sulphur does not, according to the foregoing remarks, contribute much to the value of E′, whereas, on the other hand, it must be very detrimental to the metal of the ordnance. For the mixture

$$16KNO_3+22C+8S$$

we have E′ = 16.84, hence, only 0.67 per cent. less than for $16KNO_3+24C+16S$.

If carbon and sulphur undergo a further diminution, the decrease of E′ becomes more rapid; for

$$16KNO_3+21C+4S$$

E′ = 16.54. If, therefore, we had to choose between the two mixtures

$$16KNO_3+24C+16S$$
$$\text{and } 16KNO_3+22C+8S$$

for the composition of a service powder, the second would recommend itself as the more suitable.

We will now compare the composition and energy of the ordinary gunpowders with the results of the foregoing theoretical considerations.

The composition of the powders of Waltham Abbey can be represented by the symbols:

$$16KNO_3+21.18C+6.63S$$

which corresponds nearly to 75 parts of saltpetre, 10 parts of sulphur, and 15 parts of charcoal.

About these numbers fluctuate the compositions of the service powders of most nations.

	Composition of Gunpowders.		
	Saltpetre.	Charcoal.	Sulphur.
England	75	15	10
Sweden	75	15	10
Russia	75	15	10
Prussia	74	16	10
Saxony	74	16	10
United States	76	14	10
Austria	75·5	14.5	10

If, therefore, the composition of a gunpowder is required which shall possess nearly the greatest energy, and at the same time contain the smallest amount of sulphur compatible with this condition, an experience extending over 500 years has selected a mixture which contains saltpetre, carbon, and sulphur nearly in the theoretical proportions.

Composition of powders of Waltham
Abbey . . . . . $16KNO_3 + 21.18C + 6.63S$
Theoretical composition . . . . . $16KNO_3 + 22C + 8S$.

We concluded from Karolyi's experiments that the most inflammable and combustible mixture is represented by

$$16KNO_3 + 13C + 5S.$$

Bunsen and Schischkoff found in their sporting powder

$$16KNO_3 + 13.3C + 6.3S.$$

The value of E′ for the proportions of saltpetre, carbon, and sulphur exhibited in the powders of Waltham Abbey is very nearly 16.62; for Bunsen and Schischkoff's sporting powder 14.58. Consequently 1.22 per cent. of the energy of the English service powder has been sacrificed in order to obtain the greater combustibility of the sporting powder.

According to composition, the service powders of France, Spain, Belgium, and Würtemberg are intermediate between the two powders just considered. They fluctuate about the proportions required by the symbols

$$16KNO_3 + 16C + 8S$$

E′ for these powders equals 15.63, or about 6 per cent. less than for the English; but they will, probably, be more inflammable and combustible than the latter.

It is worthy of notice that the points which represent, by their coordinates, the proportions of saltpetre, carbon, and sulphur in the gunpowders considered in this paper, are situated between two ordinates on our triangle B C D, for which respectively z assumes the values 5.5 and 8.7. The powders of Waltham Abbey, and Bunsen and Schischkoff's sporting powder contain per 16 mols. of saltpetre, nearly the same amount of sulphur; the former are represented by a point near the line D C, the latter by one near the line B D, of our figure B C D.

Summary of the Main Results.

1. The mean composition of the powders of Waltham Abbey can be represented by the symbols:

$$16KNO_3 + 21.18C + 6.63S$$

A powder of this composition is transformed in Noble and Abel's apparatus according to the equation:

$$16KNO_3 + 21C + 5S = 5K_2CO_3 + K_2SO_4 + 2K_2S_2 + 13CO_2 + 3CO + 8N_2 \qquad (II)$$

The residue of the sulphur, 1.63 atoms, unites partly with hydrogen, partly with the iron of the apparatus.

2. The ordinary service and sporting powders contain for every 16 mols. of saltpetre from 13 to 22 atoms of carbon, and from 5.5 to 8.7 atoms of sulphur.

3. A powder composed of *pure* carbon, saltpetre, and sulphur furnishes by its *complete* combustion potassic carbonate, potassic sulphate, potassic *disulphide*, carbonic acid, carbonic oxide, and nitrogen, as chief products.

4. An increase of pressure appears, *cæteris paribus*, to diminish the amount of carbonic oxide, and, in consequence, according to equation (VIII), to increase the quantities of potassic carbonate, potassic disulphide, and carbonic acid, and diminish that of potassic sulphate. These fluctuations depending on pressure are, however, *very small*. In Noble and Abel's Experiment No. 38, the pressure amounted to 18.6 tons, in Experiment No. 77 to 31.4 tons on the square inch,

Experiment No. 38 gave for every 16 mols. of decomposed saltpetre 3.36 mols. of carbonic oxide, and Experiment No. 77, 2.9 mols. of this gas, or, for a difference of 12.8 tons in pressure, one of 0.46 mol. of carbonic oxide. A diminution of 0.5 mol. of carbonic oxide corresponds to one of 0.143 mol. in the amount of potassic sulphate, and an increase of 0.071 mol. in that of the potassic carbonate and disulphide, and 0.428 mol. in the quantity of carbonic acid. These fluctuations are probably not caused directly by the pressure, but by the differences in the rate of cooling after explosion.

5. The combustion of gunpowder takes place in two stages, one succeeding the other.

(*a.*) A process of oxidation during which potassic and sulphate, carbonate, carbonic acid and nitrogen, and, *perhaps*, some carbonic oxide, but no potassic disulphide, are produced.

(*b.*) A process of reduction during which carbon and sulphur left free at the end of the first stage react with some of the products formed during that stage; the free carbon reducing potassic sulphate, with formation of potassic disulphide, potassic carbonate, and carbonic acid; the free sulphur decomposing potassic carbonate with the production of potassic disulphide, potassic sulphate, and carbonic acid [equations (V) and VI)].

6. The first stage of the combustion, the explosion proper, takes place with powders of various composition according to equation:

$$10KNO_3 + 8C + 3S = 2K_2CO_3 + 3K_2SO_4 + 6CO_2 + 5N_2 \quad . \quad (III)$$

But as some carbonic oxide is probably produced at the same time, the following will more correctly represent the reactions:

$$16KNO_3 + 13C + 5S = 3K_2CO_3 + 5K_2SO_4 + 9CO_2 + CO + 8N_2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (IV)$$

The constituents of the powder and the products of combustion are, according to (IV), nearly in the same ratios as according to (III).

7. The oxygen in the potassic carbonate stands to the oxygen in the potassic sulphate and carbonic acid, respectively, in equation (III), in the most simple ratios which can exist, if these substances are to be produced by the combustion of a mixture of saltpetre, carbon, and sulphur. In other words, equation (III) represents the most simple distribution of the oxygen of the decomposed saltpetre amongst the products of the first stage of the combustion. And

because the products are, according to equation (IV), nearly in the same proportions they assume to (III), it follows that the distribution of the oxygen between potassic sulphate, carbonate, and carbonic acid, according to (IV), nearly corresponds to the most simple possible distribution.

8. If the greatest possible amount of heat is to be evolved by the combustion of a mixture of saltpetre, carbon, and sulphur, and if at the same time potassic sulphate, carbonate, and carbonic acid are to be formed in such proportions that the heat of formation of one of them shall stand to the heat of formation of each of the others in the most simple ratio, then the combustion must take place according to equation (IV).

The heat produced by the formation of 3 mols. of potassic carbonate stands to that produced by the formation of 5 mols. of potassic sulphate and 9 mols. of carbonic acid respectively, as

$$1 : 2.05 : 1.04$$

9. The ordinary gunpowders contain more carbon and sulphur than is required by equation (IV).

This excess of carbon and sulphur is left free at the end of the first stage of the combustion.

The free carbon now acts according to equation

$$4K_2SO_4 + 7C = 2K_2CO_3 + 2K_2S_2 + 5CO_2 \quad . \quad . \quad (VI)$$

the free sulphur upon the potassic carbonate as follows:

$$4K_2CO_3 + 7S = K_2SO_4 + 3K_2S_2 + 4CO_2 \quad . \quad . \quad (V)$$

and both united form the second stage of the combustion. These reactions are endothermic; heat is not evolved but consumed; they are not of an explosive nature, and in practice are probably seldom complete.

The reactions of this second stage increase the volume of the gas formed during the first stage of the combustion and diminish the temperature of the products. A portion of the carbonic oxide is formed during the second stage by the action of free carbon or potassic disulphide upon carbonic acid.

10. The reactions represented by equations (III), (IV), (V), and (VI) can be expressed by one equation. If x, y, and z are positive numbers, and a indicates how many molecules of carbonic oxide are formed by the combustion of a weight of powder, containing x molecules of saltpetre, y atoms of carbon, and z atoms of sulphur, the

following will be the general equation representing the complete chemical metamorphosis of powder:

$$\left.\begin{matrix} x\mathrm{KNO_3} \\ +y\mathrm{C} \\ +z\mathrm{S} \end{matrix}\right\} = \left\{\begin{matrix} \frac{1}{28}[4x+8y-16z-4a](\mathrm{K_2CO_3}) \\ +\frac{1}{28}[20x-16y+4z+8a](\mathrm{K_2SO_4}) \\ +\frac{1}{28}[-10x+8y+12z-4a](\mathrm{K_2S_2}) \\ +\frac{1}{28}[-4x+20y+16z-24a](\mathrm{CO_2}) \\ +a\mathrm{CO} \\ +\frac{1}{2}x\mathrm{N_2} \end{matrix}\right.$$

11. If $x=16$, and $a=0$, the volume of the gas (V), generated by complete combustion is nearly

$$=\frac{160+20y+16z}{14} \quad \ldots\ldots \quad \text{(IX)}$$

and the units of heat, W,

$$=1000[1827.154-16.925y-8.788z] \quad \ldots \quad \text{(X)}$$

y signifies in these equations the number of carbon and z that of the sulphur atoms in a weight of powder containing 16 mols. of saltpetre.

The volume of gas becomes greater and the heat of combustion diminishes with an increase of y and z, and *vice versâ*.

The mixture containing

$$16\mathrm{KNO_3}+8\mathrm{C}+8\mathrm{S}$$

produces the greatest amount of heat and the smallest quantity of gas, and the mixture represented by the symbols

$$16\mathrm{KNO_3}+24\mathrm{C}+16\mathrm{S}$$

the largest volume of gas and the smallest quantity of heat.

12. The product E obtained by the multiplication of V and W (equations IX and X) will approximately represent the relative energies of mixtures of various composition.

The mixture represented by the symbols

$$16\mathrm{KNO_3}+24\mathrm{C}+16\ \mathrm{S}$$

is of all the infinite number of mixtures which can transform themselves according to equation (XIII) the one for which E assumes the greatest value. Hence, a powder of this composition possesses the greatest energy.

13. If a mixture of saltpetre, carbon, and sulphur were required which shall possess nearly the greatest energy, and at the same time contain the smallest amounts of carbon and sulphur compatible with this condition, theory would point to the mixture

$$16\mathrm{KNO_3}+22\mathrm{C}+8\mathrm{S}$$

The service powders of most nations fluctuate about

$$16KNO_3 + 21.2C + 6.6S$$

14. Gunpowder, however, does not contain pure carbon, but besides this element hydrogen and oxygen as constituents of the charcoal.

The oxygen is eliminated with a portion of the hydrogen in the form of water, the remainder of the hydrogen remains either free or unites with carbon, sulphur, and nitrogen respectively, producing sulphuretted hydrogen, ammonia, and marsh gas.

The secondary products only amount from 1 to 2 per cent. of the powders.

15. Mining powders contain much more carbon than is required according to equation (XIII). In consequence, the oxygen of the charcoal is not eliminated during the combustion of these powders with hydrogen, as water, but in combination with carbon as carbonic oxide and carbonic acid.

The hydrogen thus left free causes the formation of a comparatively large proportion of sulphuretted hydrogen and marsh gas. The potassic sulphocyanate is also produced in quantities much larger than those formed by the service powders on account of the carbon left free at the end of the combustion. If we neglect these secondary products, then the combustion of mining powder may be represented by the simple equation:

$$16KNO_3 + 28C + 8S = 4K_2CO_3 + 4K_2S_2 + 12CO_2 + 12CO + 8N_2$$

The reactions can also be represented as follows:

$$16KNO_3 + 28C + 8S = 16KNO_2 + 22C + 8S + 6C$$

16 mols. of saltpetre, 22 atoms of carbon, and 8 atoms of sulphur transform themselves according to (XIII) as follows:

$$16KNO_3 + 22C + 8S = 4K_2CO_3 + 4K_2S_2 + 18CO_2 + 8N_2$$

If, now, 6 atoms of carbon act on 6 mols. of CO_2 we obtain

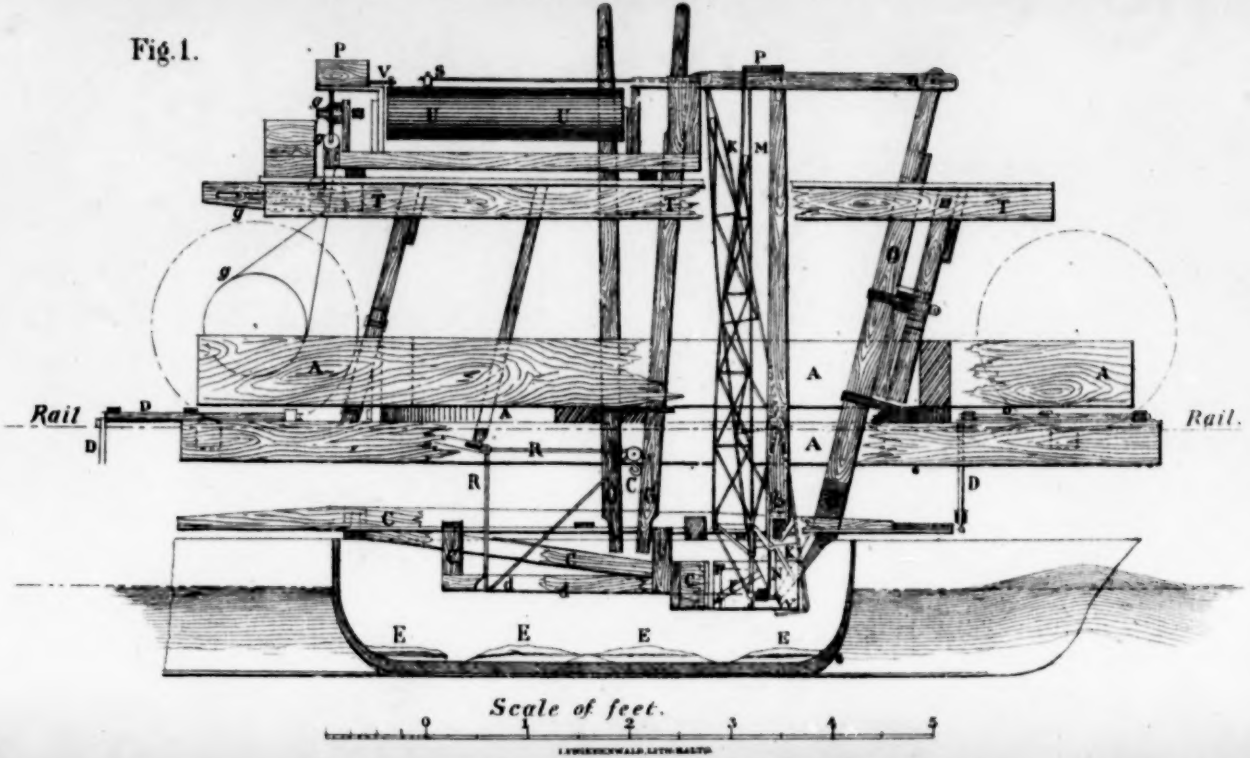
$$6CO_2 + 6C = 12CO$$

In this manner we can conceive the combustion of a mining powder to take place according to the same equations which apply to ordinary gunpowder, and that the excess of carbon in the mining powder causes, subsequently, the reduction of a portion of the carbonic acid to carbonic oxide.

Resistance of Models..

Froude's Dynamometer.

Fig. 1.



NAVAL INSTITUTE, WASHINGTON BRANCH.

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TOWING EXPERIMENTS ON MODELS TO DETERMINE THE RESISTANCE OF FULL-SIZED SHIPS.

By ASSISTANT NAVAL CONSTRUCTOR F. T. BOWLES, U. S. N.

In this paper there is compiled a brief description of Mr. W. Froude's dynamometric apparatus used in towing models, and a description of the method of obtaining from such experiments the resistance of a full-sized ship, and a summary of the most important results arrived at by Mr. Froude.

The tank in which the experiments are carried on is 278′ long, 36′ broad at the top, and 10′ deep.

The framing of the roof, which extends the entire length, carries a pair of rails 40″ apart, and 18″ to 20″ above the surface of the water. The space between the rails is free from sleepers or transverse connections of any kind.

A truck borne by four wheels moves upon these rails, actuated by an endless wire rope, which is driven by a small stationary engine having a heavy fly-wheel and very delicate and easily adjustable governor, invented by Mr. R. E. Froude, by which any speed between 100 and 1000 feet per minute can be given to the truck.

The dynamometric apparatus carried by the truck is illustrated in the outline sketch, Fig. I. The object of this is to measure and record automatically the resistance of a model, and the speed at which it is moving.

The frame *CC* is carried by the model and hung from the truck by the jointed rods *DD*, which allow it to move only in a vertical longitudinal plane, thus allowing the model to change trim, or rise

and fall bodily. This frame is counterbalanced at *W*, so that its equilibrium is practically neutral in all positions.

The resistance of the model is transmitted by the looped link *d* to the spiral spring *N*, which by its extension measures the force. This spring is fixed to the towing beam *O* forming part of the truck, and its extensions are communicated by a system of levers *KK*, *MM*, to an index arm *S*, giving horizontal motion to a pen which registers its position on a sheet of paper wound on the revolving cylinder *u*.

This cylinder revolves at a speed proportional to that of the carriage, the motion being obtained from one of the truck wheels; a second pen actuated by a clock *P* indents the paper at small equal intervals of time, thus recording the speed of the truck.

The scale of resistance is obtained by extending the spring by known weights and recording the extensions upon the cylinder as before.

The models used are made of paraffine, a convenient material; it takes a uniform polish and maintains a clean surface in water. The models are usually made to a length of about 10 feet, though tests have been made upon lengths up to 25 feet. They are shaped by an ingenious machine of Mr. Froude's invention, by which changes in form can readily be made.

We now proceed to describe some of the results obtained by Mr. Froude, whose ingenuity and skill in making and recording the experiment with this delicate apparatus, and eliminating all possible errors, was fully equalled by his wonderful powers of analysis.

By comparison of dynamometric experiments on models of different sizes, and finally by the towing experiments of H. M. S. Greyhound, Froude's Law of Comparison was confirmed, viz. "If the ship be *D* times the dimensions of the model, and if at the speeds V_1, V_2, V_3, the measured resistances of the model are R_1, R_2, R_3, then for speeds $V_1\sqrt{D}$, $V_2\sqrt{D}$, $V_3\sqrt{D}$ ... of the ship, the resistance will be D^3R_1, D^3R_2, D^3R_3 ... To the speeds of the ship and model thus related it is convenient to apply the term "*corresponding speeds*," and this being defined, we may state the scale of comparison more concisely thus: that at corresponding speeds the resistance of the model and ship are in the ratio of the total weights or displacements.

Now the total resistance of a ship at any speed—that is, the towing resistance considered apart from the action or influence of the propelling instrument—is made up of the following elements:

(1) The frictional resistance, which depends upon the area of the

immersed surface, its degree of roughness, and its length, and is not sensibly affected by the form or proportions of the ship.

(2) The eddy-making resistance, which appears in any appreciable amount only in ships of full sterns, and in ordinary cases arises from under-water projections, as shaft tubes and large stern-posts.

(3) The wave-making resistance; this is most influenced by the form and proportion of the ship, in connection with the speed.

The first two elements vary, as we know, approximately as the square of the speed, and this can be easily shown to follow Froude's scale of comparison; but we know that the resistance of ships need not vary as the square of the speed, and, as is shown subsequently in some cases, does vary according to much higher powers; this increase is due to the wave-making resistance, and shows itself at a certain critical speed at which the wave-development becomes marked.

Mr. Froude showed by reasoning from the stream-line theory that the configuration of the stream lines or of the paths of the water around the body was the same for similar forms at all speeds, if totally submerged; but the wave configurations being produced at the surface by a combination of the motion of the stream lines and gravity, these configurations will be similar for similar forms when the additional influence introduced by gravity will permit, and this will be when the velocities are as the square root of the dimensions, for the velocity of similar waves are thus related.

I have thus presented, in a condensed form, the theoretical reasoning which led Mr. Froude to anticipate the truth of the scale of comparison.

It is interesting to remark that this result was reached apparently without the aid of a proposition* in hydro-mechanics known to mathematicians which confirms this reasoning apart from the effect of friction.

In order to verify the law, an extended series of experiments was made on the various elements of resistance. I will briefly describe these, and give the results taken from the Reports of Br. Assoc. 1872 and 1874.

The experiments for frictional resistance were made upon "planes formed of board about 3-16" thick, 19" deep, and varying in length from 1 foot to 50 feet, cut-water included," and were connected with the dynamometric apparatus as already described. Along the bot-

* This proposition in its most general form is contained in Routh's Rigid Dynamics, p. 284 *et seq.*

tom of each plane, included in the depth of the 19", was a lead keel intended to give stability to the plane and to counteract its buoyancy. The planes were made as thin as possible, to have a minimum displacement and present to the line of motion a minimum sectional area as compared with their united surfaces.

This table represents the resistances per square foot due to various lengths of surfaces, of various qualities, when moving with a standard speed of 600 feet per minute, accompanied by figures denoting the power of the speed to which the resistances, if calculated for other speeds, must be taken as approximately proportional.

Under the figure denoting the length of surface in each case are three columns, referenced as follows:

A. Power of speed to which the resistance is approximately proportional.

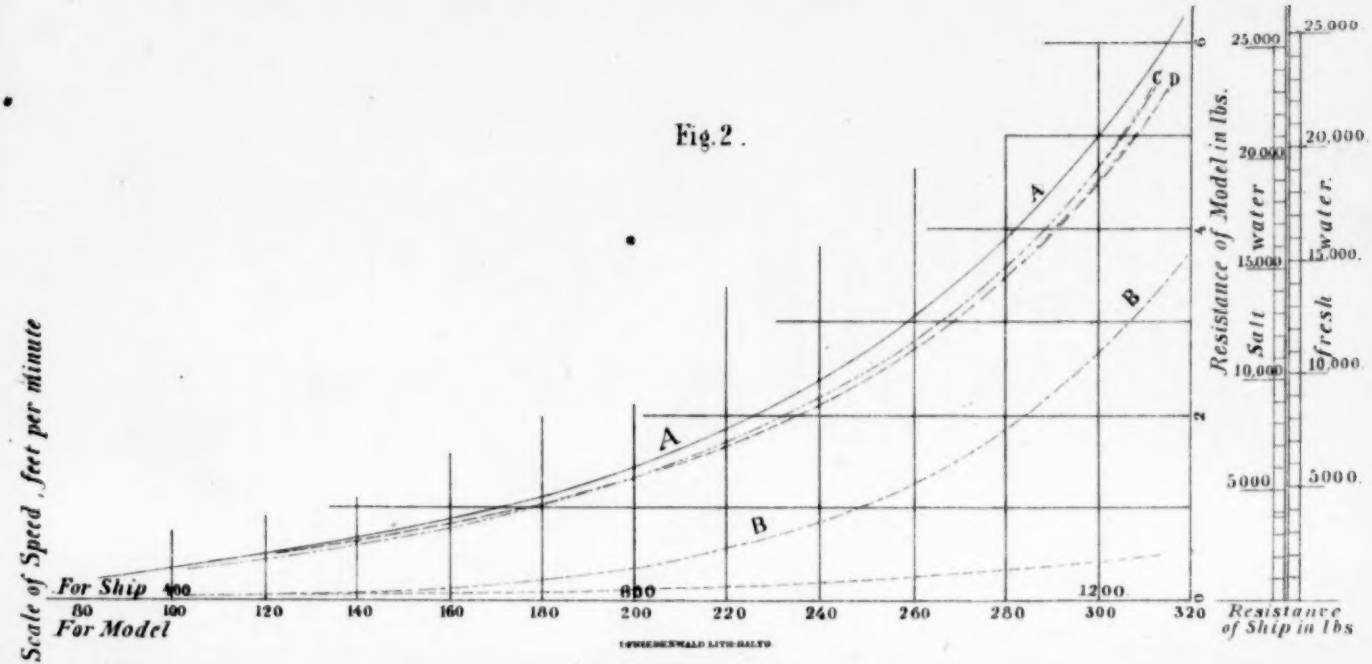
B. Resistance in pounds per square foot of a surface the length of which is that specified in the heading—taken as the mean resistance for the whole length.

C. Resistance per square foot in the unit of surface at the distance sternward from the cutwater specified in the heading.

Nature of Surface.	Length of Surface or Distance from Cutwater in Feet.											
	2 ft.			8 ft.			20 ft.			50 ft.		
	A.	B.	C.	A.	B.	C.	A.	B.	C.	A.	B.	C.
Varnish.....	2.00	.41	.390	1.85	.325	.264	1.85	.278	.240	1.83	.250	.22
Paraffine.....	1.95	.38	.37	1.94	.314	.260	1.93	.271	.237	...	...	...
Tinfoil.....	2.16	.30	.295	1.99	.278	.263	1.90	.262	.244	1.83	.246	.232
Calico.....	1.93	.87	.725	1.92	.626	.504	1.89	.531	.447	1.87	.474	.423
Fine Sand.....	2.00	.81	.696	2.00	.583	.450	2.00	.480	.384	2.06	.405	.337
Medium Sand.	2.06	.90	.730	2.00	.625	.488	2.00	.534	.465	2.00	.488	.456
Coarse "	2.00	1.10	.880	2.00	.714	.520	2.00	.588	.490	...	...	...

From this table we see that the frictional resistance generally varies in a ratio rather less than the square of the speed, that there is a great increase in frictional resistance for a comparatively small change in the degree of roughness; thus the coefficient for unbleached cotton is nearly double that of varnish, which is equivalent to a surface of clean paint, or compositions used on ships' bottoms; and the great differences in the mean resistance per square foot for different lengths of surface; thus comparing planes of 2 feet and 50 feet, the mean resistances per square foot are for varnish .41 and .25, and for fine sand .81 and .405 respectively.

Fig. 2.


Scale of Speed, feet per minute
For Ship
For Model
80
100
120
140
160
180
200
220
240
260
280
300
320
600
1200
A
B
C D
A
B
Resistance of Model in lbs.
0
2
4
6
Salt water
fresh water.
25,000
20,000
15,000
10,000
5000
Resistance of Ship in lbs

This is explained by Mr. Froude as follows: "The portion of the surface that goes first in the line of motion, in experiencing resistance from the water would in turn communicate motion to the water in the direction in which it is itself travelling; consequently the portion of the surface which succeeds the first will be rubbing not against stationary water, but against water partially moving in its own direction, and cannot therefore experience as much resistance from it." This, as we shall see, is important in obtaining the resistance of a ship from the model.

It is interesting to note that this varnished surface gave results equal to a surface coated with smooth paint or composition commonly used on the bottoms of iron ships. The frictional resistance of such a surface moving at a velocity 600 ft. per minute would be about one-quarter pound per square foot of immersed surface, which would give a frictional resistance of about 1 lb. per square foot when moving at a speed of about 12.8 knots per hour.

With regard to eddy resistance the formula used for a plane surface is approximately: Resistance in lbs. $= 1.12\, V^2 A \sin \phi$, where $V =$ speed in feet per sec., $A =$ area of plane in square feet, $\phi =$ the angle of the plane to line of motion. Thus for an area of 1 foot moving normally at speed of 10 feet per sec. the resistance would be 112 lbs.

Wave resistance can only be ascertained by direct experiment.

To obtain the resistance of the ship from that of the model. By means of the dynamometer we obtain the resistance of the model at certain speeds, and these laid off with ordinates speed and resistance in lbs. give the curve of resistance $A\,A$ (Fig. 2) of the model. Now if the law of comparison were exactly true we should only have to alter the scales of the ordinates by dividing the unit of speed by $\sqrt{D}$, D being the ratio of dimensions, and dividing the unit of resistance by D^3, but as the surface of the ship is much larger than that of the model and of different roughness, we must correct the part of resistance due to surface friction. Thus the surface of the model having been accurately found, we estimate the friction at various speeds, and deducting it from the ordinate of $A\,A$ obtain the curve $B\,B$, representing the remaining part of the resistance. We now calculate the frictional resistance of the ship, and on the proper scale add it to the ordinates of $B\,B$, and thus obtain the curve $C\,C$ or the curve of resistance of the ship as deduced from the model.

$D\,D$ is the actual curve of H. M. S. Greyhound, the result of the

towing experiments upon this full-sized ship as given in *Trans. Inst. Naval Architects*, 1874, and as shown, agrees almost exactly with the curve obtained from the model.

From this we can calculate the effective horse power with any speed, thus E. H. P. $= \frac{\text{Resistance in lbs.} \times \text{speed in ft. per min.}}{33000}$

For the Greyhound at about 10 knots the $\frac{\text{E. H. P.}}{\text{I. H. P.}} = .42$. Mr. Froude assigned the values .37–.40 as average values for single screw steamers at full speed. But this has been much exceeded by the fine formed transatlantic steamers built within the last five years, and by the latest turn-screw ships in the English navy, .48–.52 having been obtained.

I have calculated here, as a matter of interest, the ratio of the frictional to the total resistance of the ship.

Speed.	Total resistance in tons.	Per cent. of resistance due to friction.	Power of speed to which resistance is proportional.	Ratio of resistance to displacement.
4	.6	.95	2.09	
6	1.4	.87	2.09	
8	2.5	.73	2.09	$\frac{1}{170}$
10	4.7	.60	2.8	$\frac{1}{130}$
12	9.0	.43	3.5	$\frac{1}{130}$

I shall now introduce one or two examples of speed curves in order to show the practical application of this experimental work.

As an example of the application of this law of comparison and a curious case in which the resistance of a large and of a small ship at the same speed tend to become equal, is the following taken from Mr. Froude's paper on "Useful Displacement of Ships."

If R_1 = resistance of small ship at V knots per hour, then R_2 = resistance of large ship which is D times the dimensions of the small one at $V\sqrt{D}$ knots $= R.D^n$.

Now, if the resistance of the small ship varies as V^{2+n} then at a speed $V\sqrt{D}$ its resistance will be $R_1\left(\frac{V\sqrt{D}}{V}\right)^{2+n} = R.D^{\frac{2+n}{2}}$

And hence the resistance of the large ship at speed of $V\sqrt{D}$ knots is to the resistance of the small ship at the same speed in the ratio $\frac{R.D^n}{R.D^{\frac{2+n}{2}}} = D^{\frac{2+n}{2}}$ and if $N = 4$ their resistances are equal.

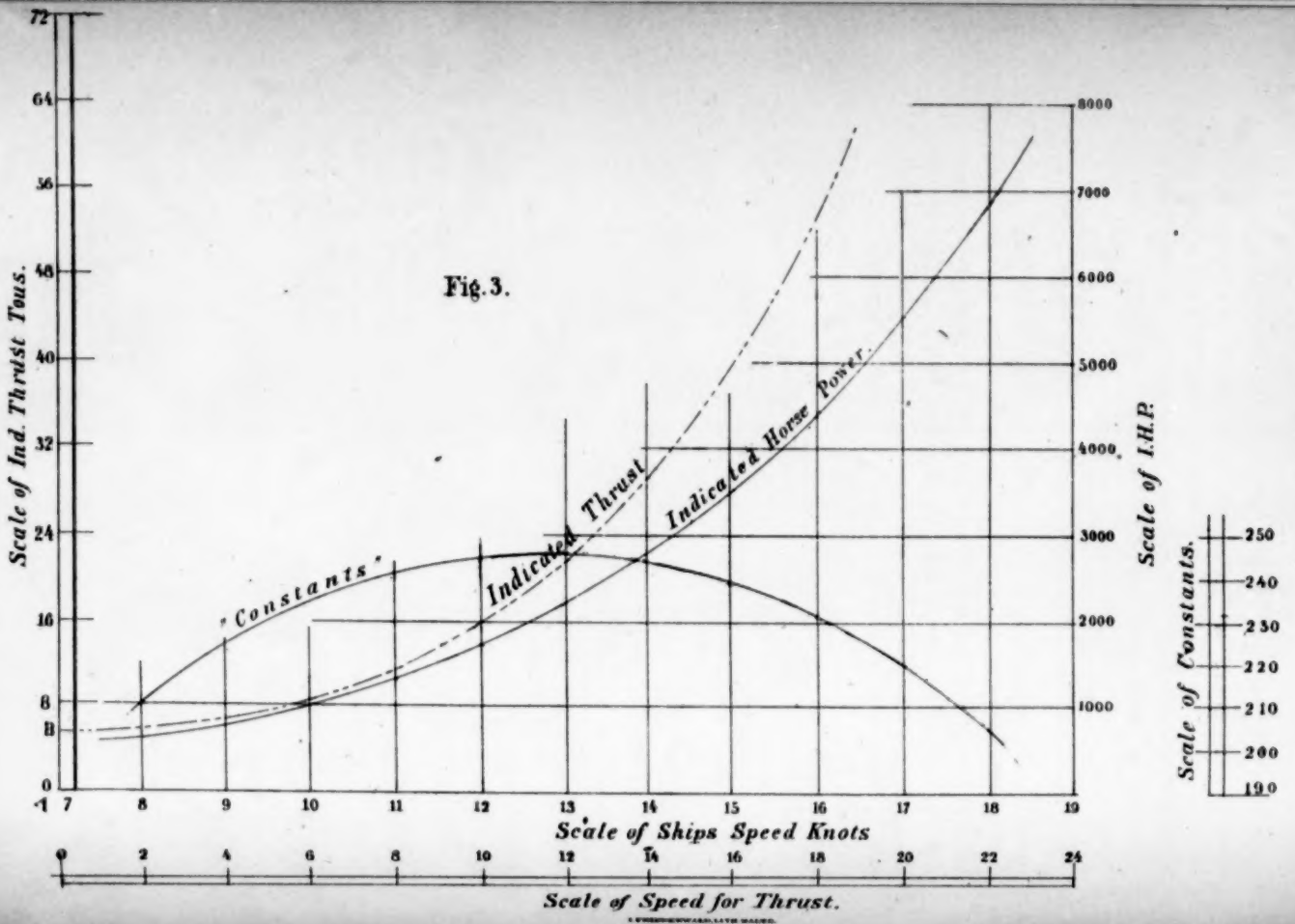


Fig. 3.
Scale of Ind. Thrust Tons.
72
64
56
48
40
32
24
16
8
0
Scale of I.H.P.
8000
7000
6000
5000
4000
3000
2000
1000
Scale of Constants.
250
240
230
220
210
200
190
"Constants"
Indicated Thrust
Indicated Horse Power.
7
8
9
10
11
12
13
14
15
16
17
18
19
Scale of Ships Speed Knots
0
2
4
6
8
10
12
14
16
18
20
22
24
Scale of Speed for Thrust.

Speed curves, as of course you are aware, are obtained by progressive trials of ships upon a measured mile, that is, each spot on the curve is the result of generally four runs back and forth across the mile, the turns being made at the same speed, and the revolutions of the engine being kept as nearly as possible constant. The engine counter is noted going on and off the mile, and indicator diagrams taken as rapidly as possible. Their data when worked up give one spot on the curve; others are obtained in a similar way at different speeds and powers.

The curve given in the diagram (Fig. 3) is that from H. M. S. Iris, taken from Mr. Wright's paper on Steam Trials of Iris, *Transactions Institute Naval Architects* for 1879. The curves shown there were obtained with great care, in order to determine the efficiencies of different screws, and are very instructive.

As a matter of interest I have calculated the powers of the speed at which the I. H. P. varies at different speeds, and have also shown the curve of indicated thrust obtained thus:

$$\text{Indicated thrust} = \frac{33000 \times \text{I. H. P.}}{\text{Pitch of screw} \times \text{revolutions per minute.}}$$

Speed.	Power at which Ind. Thrust varies.	Power at which indicated horse power varies.
4	2.3	
6	2.5	
8	2.5	2.5
10	2.5	2.9
12	2.5	3.2
14	2.6	3.4
16	2.9	3.7
18		

Each ordinate of this curve* is proportional to the mean pressure on the piston at the corresponding speed. This curve we see does not come to zero where the speed is nothing, but the remainder $A\,B$ represents the work done in overcoming the constant friction of the mechanism; and hence, if we measure from a line through B, we get our ordinates which are approximately proportional to the actual thrust, this being greater than the towing resistance by the augmentation due to the screw, and including the work lost in the variable friction or that due to the load, the oblique action of the screw, &c.

* NOTE.—An actual ordinate of this curve is obtained for the lowest speed at which the ship is tried, and the remainder is constructed according to the parabolic method given in Mr. Froude's paper on Pitch Slip and Propulsive Efficiency.

We thus obtain a comparative curve of resistance of the ship. By comparing these curves with the curve as obtained from the model we obtain the ratio of the modified thrust to the towing resistance or the effective H. P. with the I. H. P., and hence obtain a coefficient which may be used in similar ships to estimate the I. H. P. required for a given speed.

Mr. Froude did actually experiment with models carrying a screw behind, turned by apparatus carried by the dynamometer, in order to measure the augmentation of resistance due to the action of the screw.

One of the most important uses of the law of comparison is in calculating the speed and corresponding power required for a ship which is to be similar in form but of different dimensions from a given ship for which we have a speed curve and a curve of indicated thrust as shown for the Iris. Using this as a curve of resistance by measuring from a base line down through the point where the curve cuts the zero speed ordinate, we can calculate the resistance for corresponding speeds of the new ship, and thus construct a new curve of indicated thrust. This method is extensively employed among naval architects.

In making these comparisons, it should be remembered, however, that the modified curve of indicated thrust contains elements mentioned above which vary with the type of propulsive machinery.

Another useful result of this law is that it may be easily shown that what is known as the displacement coefficient $(\text{Speed})^3 \times \text{Disp.}^{\frac{2}{3}} \div \text{I. H. P.}$ is constant for similar ships of corresponding speeds. It is very common to use the so-called constants, the preceding and $(\text{Speed})^3 \times \text{area Midship section} \div \text{I. H. P.}$ in estimating power for new ships, therefore I have shown a curve on Fig. 3 which gives the displacement constant for each speed of the Iris, and we can readily see how far from constant it is.

As to the practical value of a model tank it must not be supposed that it will enable us to discover the form of least resistance, because even if such a form existed, many conflicting conditions which must be attended to in a design would limit its application; therefore in these experiments we seek only to determine a form of least resistance compatible with the governing conditions.

Apart from this, our lack of experience in the U. S. Navy with modern ships entails great uncertainty in obtaining desired speeds, and emphasizes the advisability of experiments.

The Admiralty Experiments Works at Torquay are constantly busy.

The Dutch have such an establishment at Amsterdam under the direction of the distinguished Dr. Tideman, Chief Constructor. I

have understood that the Russians constructed an apparatus after Mr. Froude's model. The French are supposed to conduct such experiments at Brest, and the well-known firm of shipbuilders on the Clyde, Messrs. Wm. Denny & Bros., have lately built for their sole use the best equipped experimental tank now existing.

I wish now to go slightly outside the scope of this paper to make a few remarks concerning measured mile trials. Let me say in the beginning that in advocating such trials I think they must be entered upon with a true spirit of scientific research, and not for claptrap or to form a complimentary page in King's or Brassey's compilations. There is considerable to be said on this question, and though I cannot go as fully into it as it deserves, it may be safely stated that it is the only way of obtaining any satisfactory and reliable information of the results and efficiency of the propelling apparatus. Consider how much instructive data was obtained with the trials of H. M. S. Iris, as given in *Transactions* of 1879, and the faults in her screws, determined to a great degree of accuracy.

Upon a measured mile trial of comparatively short duration we have it in our power to make the conditions of trial in regard to coal, state of sea, efficiency of the firemen, and uniform care in registering the results and observations, as nearly as possible the same for all ships, and thus have a degree of comparison which can never be obtained from sea trials or the records of the log, where some piece of information important to the naval architect, for instance, the exact draught of water, is sure to be lacking.

Measured mile trials are continually sneered at as "spurts," the result of "bottling up," and because ships do not make their trial speeds at sea on long voyages.

A ship at sea does not maintain her speed because the power is not maintained, and it cannot be expected that on long voyages the same work can be got out of the boilers and machinery as when every part is in the best possible condition and managed by picked men. In fact, if 75 per cent. of the maximum power is maintained, the result may be considered very satisfactory. Special means, for instance air-tight fire-rooms and forced blast, should be provided for working up to the full available power.

But apart from this, the question is to obtain a correct relation between the power, consumption of coal, and speed, and it is now widely recognized that the only results that can be reasonably trusted are those obtained from systematically and well-conducted measured mile trials.

DISCUSSION.

LIEUTENANT T. B. M. MASON.

Mr. Chairman:—I have listened with great interest to the remarks made to us this evening, and am particularly pleased to hear speed trials over the measured mile so ably advocated. Many officers ridicule the results of such trials because they are never duplicated on service. Such is undoubtedly the case, because the conditions are never again exactly the same. A moment's thought shows us that the same argument would hold good against any other trial. That this latter is the case can easily be shown by the very different speeds attributed in different official reports to the same vessel. In all comparative measurements there must be a standard unit; if there is none we have no starting point for the comparison. The unit for comparisons of speed must be either one of time or of distance.

If the measured mile is adopted, the comparison is made between the times required by different vessels or the same vessel under different conditions to accomplish the run.

If the hour trial is adopted, the comparison is made between the distances run by different vessels or the same vessel under different circumstances in the specified time.

The results of either of these trials, if carefully made, are of the greatest value to the naval architect, and serve as relative figures of merit between vessels, or different modes of running the same vessel.

There is another series of trials which I should have liked to have heard something about in connection with those over the measured mile. I refer to the turning trials of ships, which give results equally important for the study of the naval architect. In order that accurate results may be obtained for comparison between ships and steering gear it is absolutely necessary that these trials should be made under exactly similar circumstances, and that the ship should be uninfluenced by current, wind or sea.

Trials of speed and turning should be made on service under all the varying circumstances of a cruise, and the results of these trials should be tabulated for the use of those who are called upon to handle the ship, and should be reported in order that they may be compared with the results obtained under the most favorable circumstances for the study of the naval architect.

The towing tank advocated by our lecturer would soon pay for itself many times over in providing a practice ground for inventors, thus saving the government the cost of building ships on untried models.

P. A. ENGINEER JOHN C. KAFER.

Mr. Chairman:—I desire to express my high sense of the value of the paper just read, and to no one person are we more indebted for what knowledge we possess of the resistance of ships than to Wm. Froude. By the result of *his* experiments and reasoning the theories formerly advanced have fallen into

disuse. The old mid-ship section and displacement two-third power formula, with their constants, have been laid aside, and when making the computations for the power required to drive new ships—having the drawings only, and not the models—we must use either the augmented surface rule, or calculate separately the frictional, wave-making and eddy resistances. The frictional resistance is very easily calculated, and with well-shaped ships it forms at low rates of speed the chief resistance, but at the higher speeds, and with misshapen vessels, we find that the power expended in producing waves and overcoming the resistance due to eddies is a large percentage of the useful power. These two elements of the resistance of ships are of such a nature that it is almost impossible to make any correct calculation of the resistance of an intended ship.

But when we have fully proved the accuracy of Froude's law of comparisons (and I may say that this law is generally admitted to be correct by the majority of persons whose business it is to calculate the power required to drive a vessel a given speed, though not fully proved to be so), and having a machine such as has just been described, then we can get at the resistance of a ship with almost an absolute certainty. But this resistance, in the case of the Greyhound, was about 40 per centum of the indicated horse power developed by the engines to maintain the same speed. The resistance taken in the Greyhound experiments was tow-rope resistance, and not the thrust on the propeller shaft; and as there is such a vast difference between the indicated horse power developed to drive a ship, and the power necessary to tow her at the same speed, which is not satisfactorily accounted for to me by Mr. Froude, I hope that some experiments will be made to determine the actual thrust on the shaft and the resistance by tow-rope.

Whatever the difference may be, it can only be caused by the action of the screw in decreasing the actual head of water at the stern, apparently making the ship run up hill.

In a paper by Mr. Froude about 1877, on the effect of a parallel middle body, it was shown that the introduction of the parallel middle body not only increased the resistance due to the friction of the skin, by reason of the added area, but the wave-making resistance was apparently greater. It was probably the same whether the ship was long or short, but in one case the wave generated by the bow passed the ship with the crest under the counter, while if the ship were longer or shorter the hollow of the wave would be in this position.

I am by no means certain that a dynamometer would give all the resistance due to wave-making, if the determination is made from a model and the application made to a full-sized ship; and to determine the effect of the wave crest or hollow on the stern of a ship, the longitudinal change of time should be carefully noted for each speed, and if possible the contour of the wave marked under the counter.

What we need more than anything else are carefully conducted experiments on the disposition of the power of marine engines, in order to form a correct estimate of the relations of the net to the indicated horse power; then, with a

tank and a good dynamometric apparatus to determine the resistance of models, we can say with some certainty what the speed of an intended ship will be with a given power.

To show that two ships with equally fine lines, to make the same speed, the smaller requires a much greater power, I will take the Iris and the old Wampanoag, now the Florida. The Iris had a displacement of about 3200 tons on her trial, though with everything on board she displaced 3780 tons, while the Wampanoag had a displacement of about 4200 tons. To make a speed of 17 knots the Iris required about 7000 indicated horse power, and the Wampanoag to make the same speed required but 5000 indicated horse power. Surely this difference cannot be due to the fact that one vessel was sheathed with copper and the other had a painted steel surface in contact with the water.

I wish to say a few words about measured mile trials.

If they are carefully and honestly made we can get the absolute number of revolutions of the shaft while the ship has moved a mile at a given speed, and the indicated horse power to maintain this speed; and the measured mile trial has no other value, unless many runs are made at varying speeds in order that a progressive speed curve may be plotted. I think this information of sufficient value to have every ship tried over a carefully measured mile at such speeds as can be maintained for at least 24 hours, with ordinary fuel.

The Iris is credited with a speed of 18.5 knots over the measured mile, but this was done with a displacement of more than 500 tons less than when ready for sea, and burning Nixon navigation coals. I do believe that she can maintain a speed of over 16 knots at sea for 24 hours with ordinary merchantable coal and all her weights on board. The Wampanoag made 17 knots or nearly that for 24 hours, 15 or 16 years ago, and if her hull was sound could in all probability make that speed to-day.

I congratulate Mr. Bowles on his clear explanation of these towing experiments, and I am sure that his paper will be read with great interest. I hope that he will give the Institute at some time a popular paper explaining the rolling of ships, the effect of raising, lowering and winging out of weights.

ASSISTANT NAVAL CONSTRUCTOR R. GATEWOOD.

Mr. Chairman:—Mr. Bowles has asked me not to omit a few remarks which I intended to make on matters bearing upon his paper, and as the subject of augmented surface has also been referred to by Mr. Kafer as useful to the naval architect, I will first state as briefly as possible my conception of the use or uselessness of Rankine's celebrated formula. In the first place let us examine what are the grounds on which it rests. The assumptions are (1) that the resistance of ships commonly consists almost entirely of surface friction; (2) that this resistance varies as the square of the speed for ordinary ships' surfaces, and has a value of one pound per square foot at a speed of about ten knots per hour; (3) that the rubbing velocity of the water past the ship is at all points the same as that consequent on the stream-line motion of a perfect fluid past the ship's form; (4) that for purposes of approximation to the mean

square of the rubbing velocity the motion may be considered with sufficient accuracy, as equivalent to stream-line motion, past trochoidal layers corresponding to the water-lines, of maximum obliquity to the line of motion equal that of these water-lines.

To what extent are the above conditions fulfilled in practice? It must be generally admitted that the experimental results obtained by Mr. Froude given in the paper as bearing upon this point are certainly much more applicable than any similar information available to Prof. Rankine when he originated his formula. We will accordingly examine the conditions by the light of these results, although they will be found to break down without their aid.

As to the first condition, if we are content with keeping within its limitations, no fault can be found with it. But as has been shown in the paper, for every ship's form there is a certain speed beyond which the wave resistance asserts itself and increases rapidly over the frictional resistance, and this speed falls much within the limit of maximum speed of any ordinary war-ship. Accordingly we must not attempt to apply the augmented surface method to reasonably *fast* ships.

The second condition we must modify in accordance with Mr. Froude's results as given in the paper. It will be then found that for clean painted hulls or surfaces coated with ordinary ship's compositions, the law of the resistance in terms of the speed is considerably below that of the square, and also that the correct unit is one pound for about 12.8 knots, instead of 10 knots. These two corrections both tend to bring the resistance curve of ships at low speeds—when the resistance is practically wholly frictional—below the corresponding curve as calculated by augmented surface.

The third condition brings us to the vital error in the method—an error in its principle and not its application. Its source is fully expressed in Mr. Froude's words in the paper; in brief, since the water drags the ship backward, it is an immediate consequence of Newton's third law that the ship should drag the water forward. Hence the rubbing velocity cannot be in accordance with the stream lines of a perfect or frictionless fluid past the ship, but must be less. How much less was always a question until the indefatigable Froude investigated this link in the chain of a ship's resistance, and showed what a formidable thing was the *frictional* wake in ships. He proved conclusively that the frictional wake consists of a narrow following stream of velocity increasing from the boundaries towards the centre, where its velocity is always very considerable, amounting in many cases to from six to seven knots in long ships moving at from thirteen to fifteen knots. This result rigidly derived in its general nature from the laws of mechanics and carefully corroborated and quantified by experiment, at once overthrows the augmented surface method on its own assumptions.

We will however continue the examination of its fundamental conditions. The fourth condition, as is of course well known, excludes all bluff ships from the scope of the rule, since their water lines are very different indeed from trochoidal profiles. It may be useful to note as an example, that as commonly determined, the augmented surface of the Greyhound, a full ship,

in her experimental condition was 13,250 square feet, while her actual immersed surface was 7540 square feet, an enormous difference. It may be conceded, however, that Professor Rankine never intended his method to be applied to such round bodies.

We have seen that the method of augmented surface is vitally defective in principle. Some one may still say, "How about the Warrior and other ships for which its results agreed very exactly with practice? No matter how incorrect the theory, if the rule is of practical use, that fact cannot be gainsaid." The facts are these: Since the "coefficient of augmentation" is a function of the form of the ship only, it is constant at all speeds, and it accordingly follows from what has been said that the corresponding resistance curve of any ship will be a hyperbola, the constant being a resistance of one pound for one square foot of augmented surface at a speed of ship of ten knots. Now we have seen from the paper what is the nature of the actual resistance curve for ships, viz. that at low speeds the resistance is practically frictional only, and as, calculated from Mr. Froude's experimental values, it has a smaller constant and increases at a slower rate than the augmented surface curve. It accordingly falls below the latter for such speeds. But as the critical speed is approached the wave making element appears, causing a resistance the exact law of which varies in differently formed ships, but which is always much higher than the square of the speed. The actual resistance curve therefore, increasing at a more rapid rate, crosses the augmented surface curve at some speed, beyond which it rises much above it. Accordingly, both below and above this particular speed there is a discrepancy between the two, which increases as we recede from it, although the two again coincide at the zero of speed. The difference is of course much greater for a given value above the particular speed than below, which accounts for the marvellous performance sometimes predicated of high speed ships powered by this method.

There is only one more point of interest in this question of augmented surface. Some people profess no confidence in the old displacement and midship-section rules, but still think that in a new design they have something to lean on in the augmented surface method. It may however be simply shown that these three rules must stand or fall together. The displacement rule is:

$$\text{I. H. P.} = \frac{\text{Disp't}^{\frac{2}{3}} \times V^3}{C_1}$$

The midship section rule,

$$\text{I. H. P.} = \frac{\text{Area of midship sect.} \times V^3}{C_2}$$

The augmented surface rule,

$$\text{I. H. P.} = \frac{\text{Augmented surface} \times V^3}{C_3}$$

The curve of constants C_1, C_2 and C_3 must therefore in any case be *identical*, each read to the proper scale. It is shown in the paper how far from constant their values are for the same ship at different speeds, and it immediately follows that none of them can be accurately used except for *similar* ships at *corresponding* speeds, when one is as useful as the others.

I should like to say just a word on the subject of measured mile trials. The full power measured mile run is, as you have remarked, Mr. Chairman, of great use as a basis of performance, both of the same ship under different conditions and of more or less similar ships under the same conditions. A very necessary test of the efficiency of the machinery and boilers in a 6-hour full power run should, however, always be made in this connection.

There is one feature of measured mile trials which I do not think is sufficiently appreciated, or they would invariably be undertaken in all cases. I refer to *progressive* speed trials, such as recorded in the diagram shown by Mr. Bowles of Mr. Wm. Denny's ship, Merkara, and the information to be derived from the curves so obtained. Let us ask ourselves what experimental values are necessary for the analysis of the efficiency of each link in the chain of power, from the pound of coal to the ton weight propelled at a certain speed. The total efficiency will be found to be made up of the following factors :

(1) The efficiency of the boilers, measured in pounds of steam of observed pressure and condition generated per pound of coal burned.

(2) The efficiency of the steam, measured in indicated horse-power per pound of steam passing through the engines.

(3) The efficiency of the mechanism, measured in horse-power delivered to the propelling instrument per I. H. P. exerted by the steam on the piston.

(4) The efficiency of the propeller, in known resistance overcome per H. P. delivered to it at the particular speed. In this is included the effect of augmentation due to the screw.

(5) The efficiency of the ship's form measured by the actual resistance at the given speed.

We have then five links in this chain, of which numbers (1), (2), (and (3) *approximately*) may be obtained by experiment on the motive power according to methods well known to the marine engineer ; (5) can be obtained only from model experiments or by actually towing the ship. Now how is (4), the efficiency of the screw, to be obtained? The answer is, only by a speed curve taken in connection with (3) and (5). Yet this result, it must be admitted, will always be of sufficient value to warrant the comparatively inexpensive experiments necessary, and I venture to recommend the study of the efficiency of the screw propeller under the various conditions of practice as very necessary and as yet comparatively undeveloped, though much expense has been uselessly lavished upon it.

In addition to (4), the curve of indicated thrust obtained from the speed curve gives us the value of (3)—which can also be otherwise approximately obtained as mentioned—as far as the constant friction is concerned, and thus gives us very useful results respecting the efficiency of various types of engines, especially for low speed steaming. Doubt has been cast upon this result, without reason, I think, on account of the great variation observed for similar engines. It need only be mentioned, however, that the tightness of journals and piston-packing, difference in workmanship and finish, and other causes, may seriously influence individual comparisons of constant friction, without affecting averages to any considerable extent.

Allow me once more to reiterate my sense of the necessity of a model tank and properly conducted speed trials for any such naval establishment as this country undoubtedly requires.

I cannot refrain from saying just a word on Mr. Kafer's comparison of the performances of the Wampanoag and Iris. I will say nothing about the actual performance of the Wampanoag, because the exact conditions of the trial as regards wind and tide and such disturbing causes are not known to me. What I do say, however, is that I cannot believe that, under the ordinary conditions of measured mile trials, the Wampanoag could or can make seventeen knots with 5000 I. H. P. Such a performance is so far above anything heretofore obtained, and the Wampanoag's lines are, in my humble opinion, so far from the best possible, that I am not willing to believe that the nature of sea water and ships' resistances are sufficiently different on the two sides of the Atlantic to render any such results possible. But all this is but an additional plea for measured mile or other trials *under standard conditions.*

THE CHAIRMAN:—Although I have read some of the papers of Mr. Froude on resistance of vessels and models, and have listened with the greatest interest to the paper prepared by Mr. Bowles, I think it hardly possible for one to discuss a subject of which Mr. Froude is so preëminently the master without the considerable study that the writer must have given to it. I rise therefore more for the purpose of asking information on a point upon which I have some doubts, than for discussion.

If Mr. Gatewood will permit me then, I will enquire from him if the "wetted surface" of Mr. Froude corresponds in any way to the "augmented surface" of Professor Rankine?

MR. GATEWOOD (in answer):—Mr. Froude makes no allowance for augmentation of the velocity of gliding, although it undoubtedly exists to an unknown extent, but has found, after much experience, that it is very nearly correct to consider the actual wetted surface as expanded into a plane of the same length as the ship, and moving with her actual velocity. A little reflection on the effect of this will show some compensation for the apparent disregard of augmentation, because we have now thrown the total area equally under the influence of the higher power of the velocity and unit of resistance at the leading edge and the lower values of the leaving edge, whereas in the actual ship the area exposed to the extreme velocities of rubbing are both less than are given by the plane assumption. The result must be greater than if we applied the observed results of frictional resistance to each longitudinal element of the actual skin supposed moving, as a plane with the ship's velocity. A certain amount of correction is thus virtually made for the unknown augmentation.

F. T. BOWLES: I wish to thank Mr. Gatewood for his kindness in reading the paper and his elaboration of the points it contained, and am exceedingly gratified by the interesting discussion the subject has provoked.

THE CHAIRMAN:—I find I was correct in my impressions, but any one who has attempted to enter into the construction of ships on this side of the Atlantic, where Prof. Rankine's "Augmented Surface" has become so generally adopted,

will find it difficult to persuade himself of the fallacy of his reasoning; and I am glad to find that we still have some support for our belief, for Mr. Gatewood has shown that at some point of the augmented resistance curve can be found the actual resistance curve in contact with it, and this point is probably at about the maximum speed of our vessels.

We have yet to see the time when we shall be called upon to deal with the higher speeds of vessels (I refer to our present naval vessels particularly) under the commonly accepted meaning of that phrase in Europe, consequently we can consider the resistance of our ten knot vessel as following the old rule, and be within reasonable limits of the truth; but as we have wisely come to the conclusion that in the small number of naval vessels we are likely to have the speed is the all-important element, how necessary it becomes to have some other method of demonstrating what results may be expected, than the calculations based on the simple plans of the vessel to be constructed.

It is no doubt correct, as intimated by Mr. Kafer, that Froude's laws are not yet complete as regards all their applications, and had the author lived he might have modified them somewhat himself; but they are based on so much more information than was evoked before his experiments were published, that we are compelled to give up Rankine altogether, or for the higher speeds at all events.

Mr. Kafer has expressed doubts as to whether the dynamometer would give all the resistance due to wave-making, and suggests that the longitudinal change of trim should be carefully noted for each speed and the contour of the wave marked under the counter, possibly when running the measured mile.

For my part I cannot see what laws can be deduced from an experiment of this kind, when performed on one vessel and applied to another of different dimensions. The wave-making power of a ship, as shown by Mr. Scott Russell, is due to the form of the entrance and the run. However the reasoning has been criticized, I think we can safely say that the form of a vessel has a great deal to do with it. Take the Trajano for instance (the Brazilian vessel that was discussed before the meeting some time ago in connection with the paper read by Lieutenant Schroeder): while she might have the same length as a vessel built in accordance with the wave-line theory, yet her form, with run commencing at the bow, did in actual practice cause the wave to follow at a distance of several feet from the stern, while in the other vessel it was under the counter. This, as a matter of course, dropped the after part of the former vessel into the hollow of the wave, making the longitudinal axis of inclination very great, while the wave-line vessel of the same length and running at the same speed had the wave lifting her stern, keeping her on an even keel, or nearly so, and making a profile of entirely different dimensions from that in the other case. I know of experiments of this kind having taken place with poor results.

We are therefore, it seems to me, forced back to the model tank, where we can not only try the different forms of vessels as shown in the model, but can draw the profile of the wave; a difficult matter in actual practice when wind, sea, tide, depth of water and other causes may combine as distracting elements.

I think, as will almost universally be the case, that the production of a paper of this kind before the Institute will bring out some points which shall be of interest to its members, even if the paper is, in itself, technical to such an extent as to preclude our discussing it as the professional does; and in this connection I would refer to the measured mile trial which has been brought up. It is true, indeed, that we must have this basis for comparing the speed of vessels; for the sea trial, while it gives the speed under varying circumstances —information that is very desirable for the commander—will produce no data upon which the architect can base the construction of new vessels, and he, at least in our service, will have to refer to the records of the trials over a measured mile for the information he needs.

This, as we have but few vessels worthy to be put on the measured mile course, will make it more apparent that the model tank, a description of which has been so ably presented to us by Mr. Bowles, will be a most desirable acquisition to our naval establishment, as affording a school for experiments not only for the navy, but for the increased merchant marine which is sure to come, and a most essential acquisition should an increased number of war vessels follow those for commercial purposes.

The question of soft coal, as has been most appropriately introduced to the meeting, is another important matter for us to consider in designing our future ships, and I can but re-echo the sentiments of Mr. Gatewood in hoping that our Advisory Board will take its important features into consideration.

I am sure no commanding officer who has tried it, even as the boilers of our vessels are at present constructed, will hesitate a moment between cleanliness and speed; and if, as has been suggested by Admiral Jenkins, politics shall be opposed to the use of soft coal, we, as a possible interested party in the future, should not fail to urge what we deem to be right.

Whatever results shall follow the production of this paper, I feel assured that all the members will view it as a most valuable and interesting addition to the records of the Institute, and that I express the sentiments of the meeting in presenting its thanks to Mr. Bowles for its contents, and to Mr. Gatewood for reading it to us in the absence of his confrere.

NAVAL INSTITUTE, ANNAPOLIS, MD.

MARCH, 1882.

ON THE RELATION EXISTING BETWEEN LENGTH OF BORE AND MUZZLE VELOCITY.

BY LIEUTENANT CHAS. A. STONE, U. S. N.

In 1875, the following experiment was made at the National Armory for the purpose of determining the length of bore which gives the maximum muzzle velocity with the Springfield rifle, using the service ammunition. A rifle was made so that the length of bore could be increased from five inches to one hundred and twenty-two inches by additional barrels. The muzzle velocity was measured with each length of bore, each muzzle velocity being the mean of ten shots. The ammunition was, of course, the same throughout the experiment. The following table, taken from the report of the experiment, Army Ordnance Notes No. XXXVIII, shows the lengths of bore and corresponding muzzle velocities:

Lengths of Bore. Inches.	Muzzle Velocity. Feet.
5.	704.
12.	1100.
22. (Carbine).	1210.
26.	1254.
32.6 (Service rifle).	1320.
42.	1345.
62.	1397.
92.	1416.
102.	1410.
112.	1420.
122.	1411.

In order to find the length of bore corresponding to the maximum muzzle velocity, I tried to find a function which would satisfy the

values given in the table. Calling the muzzle velocity v and the length of bore x, the following form was first tried:

$$v = a + bx + cx^2 + fx^3.$$

The values of the constants a, b, c and f were determined from the values of x and v given in the table by the Method of Least Squares. The values of v were then calculated for the values of x given in the table, and the calculated and measured values were compared, but the agreement was not sufficiently close to warrant the use of this form. The form $v = e^{a+bx+cx^2}$ was then tried in the same way. It more nearly satisfied the conditions and showed that this form was better adapted to the purpose than the preceding one, but the differences between the calculated and measured velocities were still too great to make it of any use as an empirical formula. The values of the constants are $a = 6.5867$, $b = .02175$ and $c = -.0001421$.

The calculated and measured velocities are compared in the following table:

Lengths of Bore. Inches.	Muzzle Velocity. (Calculated.) Feet.	Muzzle Velocity. (Measured.) Feet.	Diff's. +	Diff's. −
5.	806.	704.	102.	...
12.	923.	1100.	...	177.
22.	1093.	1210.	...	117.
26.	1160.	1254.	...	94.
32.6	1268.	1320.	...	52.
42.	1408.	1345.	63.	...
62.	1618.	1397.	221.	...
92.	1612.	1416.	196.	...
102.	1521.	1410.	111.	...
112.	1395.	1420.	...	25.
122.	1243.	1411.	...	168.
			+693.	−633.

In order to make the agreement closer another term was added to the exponent, so that the form was

$$v = e^{a+bx+cx^2+fx^3}.$$

The calculated curve has now two maximum ordinates. The minimum between them was found in the neighborhood of 102 inches, due apparently to the fact that the measured muzzle velocity for 102 inches is less than that on either side of it. This, of course, is an accidental

error, and it would seem to preclude the use of any equation of as high a degree as this unless we reject the result for the length of bore of 102 inches. This minimum is magnified in the calculated curve and the maximum ordinate between it and zero is found between 42 and 62 inches; so that the agreement is not as good as with the previous equation of a lower degree.

The next form tried was one deduced from Sarrau's formula for the muzzle velocity, which, considering all the quantities constant except the muzzle velocity and length of bore, can be written

$$v = \frac{1}{a} x^{\frac{4}{10}} \left[1 - b x^{\frac{1}{2}}\right].$$

The constants a and b were determined, as before, by the Method of Least Squares, and were found to be $a = .0021869$ and $b = .050552$. The following table gives the calculated and measured velocities:

Lengths of Bore. Inches.	Muzzle Velocity. (Calculated.) Feet.	Muzzle Velocity. (Measured.) Feet.	Diff's. +	Diff's. −
5.	772.	704.	68.	...
12.	1019.	1100.	...	81.
22.	1201.	1210.	...	9.
26.	1249.	1254.	...	5.
32.6	1311.	1320.	...	9.
42.	1371.	1345.	26.	...
62.	1434.	1397.	37.	...
92.	1437.	1416.	21.	...
102.	1423.	1410.	13.	...
112.	1404.	1420.	...	16.
122.	1380.	1411.	...	31.
			+165.	−151.

This agreement is much closer than with any of the preceding forms, although this one contains but two constants. The fair agreement throughout such a great variation in length of bore confirms, as far as this experiment goes, the employment of this function to express the relation between length of bore and muzzle velocity. From the manner in which it was determined we should expect that it would agree better than a purely general form, but how much better can only be determined by applying it to the results of experiments such as this.

From the formula

$$.0021869v = x^{\frac{4}{10}}[1 - .050552x^{\frac{1}{2}}]$$

the maximum muzzle velocity is found to be 1446 feet, corresponding to a length of bore of 77.3 inches. The form $v = e^{a+bx+cx^2}$ gives the position of the maximum ordinate nearly the same, namely, at 76.5 inches, but the corresponding muzzle velocity is too great. Since the acceleration is zero where the muzzle velocity is a maximum, this value of $x = 77.3$ inches marks the point at which the remaining pressure of the powder gas on the bullet is just equal to the friction in the bore.

Many other deductions could be made from this empirical formula, but they involve either the supposition that the curve represents the relation between v and x far beyond the values by which it is determined, or the taking of successive derivatives which may depart widely from the truth.

NAVAL INSTITUTE, ANNAPOLIS, MD.

MARCH, 1883.

THE BELLEVILLE BOILER.*

REPORT OF THE BOARD OF INSPECTION ON THE STEAM APPARATUS OF THE DESPATCH BOAT VOLTIGEUR (REAR ADMIRAL HALLIGON, PRESIDENT).

Translated by PROFESSOR J. LEROUX, U. S. N. A.

Description of the Boilers.

The last government vessel fitted with boilers (Belleville system) was the gunboat l'Epée, in 1872. Since that time the Belleville steam-generators have received many improvements. The engine of the Voltigeur contains them all, and therefore differs considerably from the apparatus of the same system previously introduced into the navy, and deserves on that account a complete description.

Grouping of the Boilers.

There are six boilers identical in shape placed back to back, three on each side of the midship line of the vessel, the whole occupying an area 16.404 ft. long by 11.483 ft. wide.

The height of the generators is 10.171 ft. above the floor, with a mean distance of 13.78 in. from the deck-beams above.

There are two fore and aft firerooms on the port and starboard sides of the ship respectively, connected by a transverse passage two feet wide.

* This boiler, similar in principle to the Herreshoff, is being tested in the French Navy in large vessels. The accompanying report and other information relating to it (see Proc. Vol. VIII, No. 4, p. 693) is furnished the Naval Institute, by the manufacturers, MM. J. Belleville et Cie, St. Denis, France. The report is slightly abridged.

Partitions and Shells of the Group of Boilers.

Each group of boilers is encased in a shell whose vertical sides are formed, to the height of the grate, by sheet-iron, to the bottom of the tubes, by fire-bricks, and to the top of the tubes, by sheet-iron. The partitions between the middle boilers are of a single sheet-iron plate 0.315 in. thick, but those encasing the outside of the group consist of two plates with an intervening space of 1.378 in. filled with a non-conducting layer of fine, well-beaten coal-cinders; they have besides a third sheet-iron plate forming an air-casing. The shells are joined on top by a double casing of sheet-iron filled up with coal-cinders.

Boiler Attachments.

As above stated, the six boilers are identical in form, and constitute as many independent generators. Each boiler is composed essentially of:

1. A tubular nest divided into five distinct elements constituting the steam generating apparatus proper.

2. A steam collecting purifier placed on the upper part of the tubular nest, and serving on one hand to collect and dry the steam before its passage to the engine, and on the other hand to free the feed-water flowing through it from the impurities it holds in suspension or in solution.

3. A feed collector at the bottom of the tubular nest furnishing water to the different elements.

4. A self-acting feed regulator.

5. A receiver for ejecting into the sea the deposits caused by the feed-water.

The tubular nest set over a furnace occupying the whole base of the shell, is alone exposed to the action of the gases of combustion; all the other attachments being outside the shell.

Combustion Furnaces.

The combustion of coal takes place in a rectangular furnace 4.593 ft. wide by 4.724 ft. long. The distance from the base of the tubes to the grate is 21.65 in. at the front, and 23.622 in. at the back.

The capacity of the furnace is 38.141 cu. ft.

The sides of the furnace are built of fire-bricks up to the tubular boiler. Originally the width and depth of the grate were the same

as that of the furnace; but as a result of the primary tests it was found expedient to reduce its surface by a stationary line of bricks five inches wide at the back and sides, laid flat on the bars, and removable at will. The surface of each grate has thus been reduced to 15.177 sq. ft. and the total surface to 91.07 sq. ft., a reduction of 24 per cent. from the original surface.

The slope of the grate is one inch in twenty. The bars, numbering sixty, have a peculiar shape, consisting of iron blades of an average thickness of .4 in. and 4 in. high, presenting, lengthwise, a series of regular undulations with an amplitude of .4 in. in height and 4 in. in length. The ratio of clear space to the total surface is exactly one-half. The maximum space between bars is .8 in. Originally there were straight bars alternating with undulating ones; the grate was then more compact, and the ratio of clear space to the total surface was one-third. The air passages were found insufficient and the straight bars were removed. This arrangement of the grates has been devised 1st, to allow the passage of but few cinders, the clear space between the bars being very narrow; 2d, to obtain a uniform temperature for all the bars, by the multiplicity and extent of contacts; 3d, to cool the grate and heat the inflowing air by means of deep bars; 4th, to preserve the grate, and avoid at the same time local overheating and reddening of certain bars, and consequently allow only a feeble adherence of the clinkers.

Owing to the great width of the furnace it was found necessary to provide it with two doors, each door being 15.75 in. wide. Each door is made in two sections. The lower section 4.72 in. high, allows the introduction of the slice-bar during the cleaning process. The upper section is used for coaling. The two furnace-doors being never open at the same time, the inflow of cold air so detrimental to the draught and combustion is limited; the working of the fires is facilitated by this arrangement, as the firemen are less exposed to the radiating heat of the furnace, which is all the more intense owing to the fire-brick lining. It should be here stated that when the brick works are heated, the high temperature in the furnace produces very rapid combustion of the fresh coal thrown upon the grate, and permits the use of the hardest kind of anthracite coals.

The above is one of the advantages claimed by M. Belleville in favor of the boilers of his system, compared with boilers having interior furnaces necessitating the use of free-burning bituminous coals.

Ash-pit.

The bottom of the ash-pit is formed by a sheet-iron pan 10 inches deep, containing constantly a certain quantity of water for extinguishing the burning cinders that fall through the grating. To prevent this water from flooding the floor with the rolling of the ship, a piece of angle-iron 3 inches high is fastened in front of the ash-pit; this plate serves at the same time as a buttress for the feet of the firemen. The door of the ash-pit is 16 inches high and 3 feet wide; it swings around a horizontal axis placed a little above the mean height. Between the vertical position corresponding to the close shut and the horizontal (wide open), it may occupy five intermediate positions, in which it is held by means of a notched rack.

In their passage from the furnace to the chimney through the tubular nests, the gases of combustion meet with a series of horizontal plates which force them to make several circuits along the tubes for the purpose of equalizing the heat.

Generation of Steam.

The tubular nest constituting the steam generator proper is composed of five distinct elements placed side by side in the boiler, and communicating with each other only by means of the feed collector at the base and the steam purifier at the top. Each element forms a coil composed of eighteen tubes arranged in two vertical rows of nine tubes each. The tubes of the two rows are connected by boxes at front and back. The lower front box, which is set directly upon the feed collector, receives the first tube of the coil—besides two other tubes; above it are seven plain boxes bearing two tubes each; finally, above the latter is the elbow that receives the last tube and communicates with the steam purifier. At the back of the nest are nine plain boxes receiving two tubes each. The two apertures in each plain box for the fitting of the tubes are in the same horizontal line, but the boxes at the back are mid-height with the boxes in front; it follows that to pass from one to the other the tubes must be inclined. All the tubes of one row of the element are parallel and incline upwards from front to back; those of the other row are also parallel, but incline upwards from back to front. If we follow the course of the coil from the feed collector to the steam purifier, we will find, therefore, a series of tubes placed alternately on each side of the mean vertical plane of the element, and always rising with a regular inclination

of one in twenty. This arrangement, peculiar to the Belleville boilers (model of 1877), constitutes an important improvement upon the preceding types, inasmuch as it increases the evaporative efficiency, allows the free escape of steam from the heated surfaces and thus avoiding the primary cause of overheating, and when the boiler is empty, prevents the local corrosion of the tubes by preventing drops of water from remaining in the nest, as occurs in horizontal tubes.

The tubular nest is supported in front by the feed collector (which itself rests upon the front bulkhead) to which it is secured. In the back it simply rests upon the brick-work, without any bracing; at the top it is fastened to the steam purifier by socket bolts (one for each element). The connecting boxes are separated from each other by means of inserted blocks. In these conditions, the expansion of the elements by the action of the fire remains perfectly free. Besides, it is very easy to separate one element from the rest of the section.

The tubes are screwed into the connecting boxes, being fitted directly into the back connecting boxes and the joint strengthened by a plain ring; the same is done in front, for all the tubes of one row of the elements, with the exception of the lower box and the upper elbow, but in the case of the other row, the connection is made by means of a collar which unites the end of the tube with a nipple screwed into the box and projecting 1.25 in. outside. By cutting this collar or cylinder and the ring that accompanies it, to consolidate the joint, the tube is isolated from the box and the coil is separated into two parts. This operation can be performed at any height of the element.

The tubes are 4 inches in exterior diameter and 0.2 in. in thickness, with the exception of the lower tubes, which, being exposed to the direct action of the fire, have a thickness of .25 in.

The tubes are of wrought iron, lap-welded. One of the tubes was cut during the repair test; it was opened in the plane of one of its generatrices and strips cut, which were then broken with the wrought iron testing machine. The results of the trial were as follows:

	Strips Cut.	
	Lengthwise.	Crosswise.
Breaking strain per sq. in.	54048 lbs.	32287 lbs.
Elongation	20.4 per ct.	1.5 per ct.

These figures place the metal of the tubes nearly on a par with the best wrought-iron; the elongations however are somewhat less.

The connecting-boxes are of malleable cast-iron. They are pierced with holes with cast-iron plugs opposite the tubes, for the purpose of examining and cleaning the interior. The exterior cleaning is done by means of the steam-cleaner and brushes. In order to facilitate this operation, two large doors are fitted in front, covering the whole height and width of the tubular nest. They are exteriorly provided with air casings and wooden lagging to prevent radiation. In normal firing, the level of the water rises in the elements to about the fourth row of the tubes. The corresponding volume of water is 17.163 cu. ft. for each generator, the volume of steam space 21.684 cu. ft. However, as will be seen further on, the water level is subject to sudden fluctuations, and these figures represent only an average.

The heating surface of each generator, including the whole exterior surface of the tubes and boxes exposed to the fire, is 508.98 sq. ft. or 25.8 times the surface of the original grates, and 33.4 times the present surface.

Fusible plugs.—A safety contrivance for warning the fireman of the lowering of the level of the water, or the superheating of the steam, should be here referred to. It consists in fusible tin plugs .2 in. in diameter, driven in the fourth and seventh row of boxes. These plugs melt at 446° F. The moment that the steam reaches this temperature the plugs melt, and the steam escapes with a peculiar hissing sound. When the water-level falls abnormally in the element, the steam in the upper tubes becomes superheated, and the plugs of the seventh row melt away. If one of the tubes of the element gets obstructed, the whole coil becomes overheated, owing to the failure of circulation of the steam, and the plugs of the fourth row are the first to disappear. The melted plugs are replaced without the least trouble and without stopping.

Drying Process, Steam Purifier.

The steam generated in the tubes carries along with it from three to six times its weight of water, the proportion varying according to the activity of combustion. The drying of the steam is therefore rendered indispensable, and is one of the operations performed by the steam purifier.

The purifier is composed of a sheet-iron cylinder 0.47 inch in thickness, 17.8 inches in interior diameter, and 4.364 feet in length, provided at each end with plugs for the purpose of examining the

interior. It rests in a horizontal position above the front boxes of the tubular nest outside the casing, and receives underneath five pipes, each of 2.8 inches interior diameter, which establish communication with the five elements.

At 2.4 inches over the orifices of these pipes is a horizontal sheet-iron plate, riveted on one side to the lateral wall of the collector, and bent on the other side so as to form one-half a cylinder concentric with the purifier, and having a smaller diameter, allowing between the two a passage 1.8 inches wide.

In order to reach the centre of the collector, the mixture, steam and water, issuing from the pipes of the elements, after being projected against the horizontal plate, must follow in an arc of 180° the annular space between the two cylinders, and as it possesses a high speed, the separation of water and steam is done mechanically by centrifugal force. To ascertain at any time when the drying is complete, two test cocks are placed, one at the entrance to the purifier and the other at the exit, which permit of judging by its appearance the state of the steam.

Separator.—The water separated from the steam goes back into the elements. The dry steam, in order to pass from the centre of the collector into the pipe leading to the engine, must go through a cast-iron tube called the separator, 3.346 inches in interior diameter and 2.950 feet in length, into which it enters through three holes 0.472 inch diameter, bored at regular intervals, the three together having an area of 0.525 square inch.* The steam finally issues from the separator through a pipe 2.76 inches in diameter inserted into the collector and connected with the exterior steam pipes. The object of the separator is to equalize the pressure of the different elements of the steam generator. The purifier not only performs the drying operation, it contributes also to the heating and purifying of the feed-water that passes through the whole length of it before it reaches the elements.

The water enters at the right-hand back corner and flows over the floor formed by the upper surface of the horizontal plate before referred to, through the whole length of the purifier, issuing at the other end and passing to the feed collector. During all its course through the steam purifier the feed-water is therefore in direct contact with the steam, and gets rapidly heated, and this sudden increase of temperature causes the precipitation of the salts and other

*This separator is apparently in the longitudinal axis of the purifier.

impurities which it holds in solution or in suspension. These impurities carried along with it into the pipe of the ejecting receiver, are afterwards blown out by simply opening the cocks.

The steam purifier is one of the new improvements of the Belleville boilers; it is an important attachment, as much on account of the steam drying operation that takes place in a sure and regular manner, as on account of the heating and purifying of the feed-water, which exerts a considerable influence upon the working and preservation of the tubular nest.

Feed.—Forced up by the pumps of the engine, the feed-water, before reaching the steam purifier, must pass through a special attachment, the *self-acting feed regulator*, which plays a most important part in the maintenance of the water level in the elements, and consequently in the production of steam.

Apparent Level.

The working of the feed-regulator is based upon phenomena of apparent level little observable in boilers having a great volume of water, but well marked, on the contrary, in boilers of the Belleville or similar systems. In every boiler in active operation the flowing of steam can only take place under the influence of a difference of pressure between the surface of the boiling water and the orifice through which the steam escapes from the boiler. The loss in the load or the diminution in the pressure of this flowing steam from the surface to the orifice is greater for a definite supply of steam:

1. As the rapidity of the flow is more considerable, that is to say, as the diameter of the moving column of steam between the water surface and the orifice is smaller.

2. As the resistances to the flow are greater. These resistances vary directly as the distance travelled and inversely as the size of the tubes traversed, and depend also on the density of the steam, or, in case of mixture of steam and water, on the density of the mixture, which is greater as the quantity of water increases.

From the fact of a difference of pressure between the water surface and the escape orifice, it results by placing alongside the boiler a vertical tube whose lower end enters the water and the upper the steam near the escape orifice, that the apparent level in the tube will be higher than the actual level in the boiler and will exceed it by a quantity which will be precisely equal to the water height corres-

ponding to the difference of pressure at the surface of the water and that caused by the steam flowing out.

If we attach the upper end at different heights in the steam space, the lower end of the tube remaining unchanged, the difference between the actual and the apparent levels will measure the loss of load between the water surface and these different points; it will go on decreasing in proportion as the upper point of attachment approaches the surface of the water.

The difference between the real and apparent levels is easily set off; the apparent level having been marked on the pipe while the boiler is in operation, it is only necessary to shut off the steam suddenly at the stop-valve. The level will then fall instantaneously in the pipe till it reaches the actual level in the boiler. The distance between the two levels thus observed equals the water height corresponding to the loss of load.

The water-pipe is attached, at the lower end to the lower connecting box, and at the upper end to the third box below the elbow coil at the top of the element, the upper end being therefore about half-way between the surface of the water and the orifice of exit. In these conditions the difference between the apparent and real levels is about 5.9 in. in normal firing and 7.9 in. in excessive firing.

Manner of Regulating the Feed.

Let us now suppose that before the entrance of the feed-water into the boiler there has been fixed upon the feed-pipe a self-acting apparatus that hermetically closes the passage, when the apparent level, as shown in the water column, reaches a definite point, which we will call the normal level, and opens only when it falls below this level; the consequence will be that the feed being stopped, whilst the apparent level remains below that point, the real level in the boiler will fall little by little, in proportion to the consumption of steam, until the moment when the apparent level, which follows its motion at a distance, reaches the normal point. The flow of the feed-water will then begin again, the level will become constant and will have thus established itself automatically in the boiler, at a distance from the apparent level, which will represent the loss of load of the outflow. The real level being thus regulated, if the combustion is accelerated in the furnace, and, consequently, the generation of steam increased, causing a greater amount of water to be carried forward with the steam, the resistance to the flow of steam and consequently the loss of load

will be greater, thus increasing the distance between the actual and apparent levels. The apparent level will then rise at first, the feeding will stop, and there will be a progressive falling of both levels until the apparent level returns to the normal point; the relative balance of the levels will then be re-established, but the real level will be lower than it was before. Thus, from the tendency to foam, the real level will have fallen in the boiler. The contrary result would have taken place if combustion had been sluggish, and if there had been a lesser tendency to foaming.

The consequence of these fluctuations of the real level, according to the activity of combustion and ebullition, is that the steam always reaches the collector in the same state of moisture, and if any change should take place in that state the boiler corrects it itself. There is, therefore, established a self-acting regulation of feed whose effect is to maintain constant the initial state of the steam.

Self-acting feed regulator.—The apparatus designed for the foregoing purpose is the self-acting feed regulator. It is essentially composed of a float placed in the water-column. The complete arrangement comprises:

1. The water-column of cast-iron, square section, 3.773 feet in height and 7.086 inches square. To the water-column pipe are attached directly the glass gauge, the gauge-cocks and the manometer gauge, whose mouth is in the water.

2. The float, composed of an iron cylinder 5.5 inches in exterior diameter and 19.685 inches in height, which works a round vertical rod of 0.787 inch, which issues from the water-column through a stuffing-box.

3. A horizontal lever transmitting the motion of the float rod to another of the same diameter bearing the regulating valve.

4. A self-acting cock, composed of a bronze curved tubing, with an interior seat for the regulating valve. The feed-water enters at one end of this tube and leaves at the other, after traversing the passage opened by the valve. The self-acting cock is secured to the water-column.

5. The regulating bronze valve, with conical seat 8 inches in diameter, with a lift of .3 of an inch.

6. A spring and a balance weight placed at the end of the horizontal lever, which together partially balance the weight of the float and its connections. The tension of the spring is steady, but the balance weight is composed of eight leaden disks that can be easily removed.

It must be noticed:

1. That the self-acting cock and the water column are entirely separated. The temperature of the self-acting cock is thus always relatively low; the valve therefore is not warped, and can only become obstructed by the impurities brought in by the feed-water.

2. That the system of levers is so designed that it is perfectly balanced in regard to steam pressure as well as to water pressure. The valve has therefore no tendency to jam, but is regulated exclusively by the float, and is sensitive to the slightest movement.

3. That the stuffing-boxes through which the rods penetrate into the water-level pipe, and the self-acting cock, are packed with anti-friction material, and are therefore very smooth and at the same time very substantial.

It is owing to these precautions that the self-acting feed apparatus possesses an extreme sensibility, while being at the same time free from any uncertainty in its action, which is the common drawback in apparatus of that kind. The inclination of the lever, placed in a conspicuous position, points out the position of the valve, and enables a person to ascertain at a glance if the regulator is in working order.

The eight balance disks of the regulator being in their places, the check valve closes completely when the water reaches a point two-thirds of the height of glass water gauge tube. This point represents the *normal level.* If we remove the eight disks, which produces the same effect as if the weight of the float were increased by a certain quantity (about eight-ninths of the weight of the eight disks), it will require a higher level to close the valve. The normal level will therefore be raised and with it the real level in the boiler; consequently we will obtain in the steam purifier steam more saturated with water. Thus, by removing one or more disks we displace at the same time both the normal and real levels, and we modify the state of the steam.

Course of the feed-water.—After issuing from the feed-pumps of the engine the feed-water passes first through a rose pierced with very fine holes, intended to prevent the impurities from reaching the apparatus of the regulators. It then passes through the pipes to the base of the boilers.

The special branch pipe of each generator leads to a graded cock, which is worked by hand, and is intended, by partially cutting off the flow of water, to relieve the automatic valves or to distribute the water equally among them when from any reason the check-valves happen to be wide open. Over the graded cock is a valve closing from the

inside, to prevent the return of water from the generator in case of a break in the feed-pipes. This valve is indispensable, the self-acting valve being balanced.

The water reaches then the automatic regulator and thence passes into the steam purifier; there it is heated, the impurities it holds in suspension or in solution are precipitated, leave the purifier with it, and follow it in the vertical pipe of the *ejector*. This pipe occupies the whole height of the tubular nest (outside the shell) and is continued by the ejector proper. The latter supports at the height of the lower coil boxes a horizontal tube, which connects with a wrought-iron rectangular tube 4.92 inches by 5.315 inches on the sides and 4.363 feet in length.

Feed-collector.—This tube is the feed-collector. It supports the twin boxes of the elements, and is connected with them by means of pipes with conical joints, which extend into the boxes through cast-iron nipples, which raise the inflow orifice of the feed-water above the bottom of the box and prevent its being obstructed with sediment. Four removable plugs facilitate the examination of the interior of the collector; a blow-off or drain-cock serves to empty it.

It has been seen that the feed is regulated automatically, not only according to the quantity of water contained in the generator, but also according to the state of the steam; that is to say, the real level in a boiler undergoes continuous fluctuations, according to the degree of activity of ebullition and combustion.

Supplementary Cistern.—The volume of the wells of the condensers and of the safety discharge-pipes, which are an immediate continuation, is too small to meet these fluctuations, and there would have been some danger of the condensed water being frequently ejected into the sea through the discharge-pipes, if there had not been provided a supplementary cistern consisting simply in a large tub, with a capacity of 1800 litres, placed under the flooring of the engine and connected by a special pipe with the horizontal branch of the safety discharge-pipes.

Blowing-out Ejector.—It has been seen that on leaving the steam-purifier the feed-water, in order to pass into the feed-collector of the elements, follows a vertical pipe with a box extension; this box forms the ejector. The pipe is of wrought-iron, its interior diameter is $3\frac{1}{2}$ in. It is connected by a malleable cast-iron elbow with the ejector; this is composed of a sheet-iron cylinder 7.87 in. in interior diameter and 35.433 in. in length. The pipes connecting it at its upper part with the feed-collector are of malleable cast-iron.

The ejector has a blow-off cock placed 10 in. from the base extending internally through a tube pointing downwards, which terminates at 5.906 in. from the bottom, and externally through a pipe which connects with the main blow-out pipe. It is, besides, provided with a cleaning digestor and a blow or drain cock.

The working of the ejector is very simple; during the passage of the feed-water in the steam purifier, the impurities which it holds in suspension or in solution are separated in a pulverulent state; they are precipitated during the flow of the water in the vertical pipe and fall to the bottom of the cistern, from which they are removed by the blow-off cock into the sea. The water flowing into the collector is therefore pure and clear.

Steam-pipes.

Each one of the steam purifiers has a steam-pipe connection forming a continuation of the pipes of the separator. From these proceed pipes 2.165 in. interior diameter, which unite with the main steam-pipe 6.7 in. interior diameter that goes from the boiler-room to the engine-room, passing through the starboard alley.

General Steam Purifier.

Before it reaches the engine the steam passes through the general steam purifier, which is intended to rid it of the water that it might yet contain, produced either by condensation in the pipes or from temporary trouble in the operation of the steam purifiers of the boilers. The main steam purifier, like the latter, dries the steam by centrifugal drying; its arrangements are similar. It is composed of a vertical cylinder 8.55 ft. high and 17.72 in. interior diameter. The steam enters through a tube situated at the top of the cylinder and in the axis; it issues through a tube situated in the upper portion of the cylinder and on one side. It cannot pass from one tube to the other, that is, from the centre of the purifier to the circumference, except by following a leading passage formed by a cylinder internal to the first and broken in a part of its circuit. The annular space between the two cylinders is 2.4 in. in width.

The water separated from the steam falls to the bottom of the purifier, and is expelled by a self-acting "snifter" which drives it into the supplementary cistern. The snifter consists in a float working a cock and balanced by an exterior weight. The cock is entirely outside the purifier. All the stuffing-boxes of the snifter are packed

with anti-friction packing. The purifier has besides a hand-snifter, and is provided with test-cocks for the purpose of ascertaining the state of the steam before and after the drying operation.

After issuing from the general steam purifier the steam traverses the valve-box of the throttle-valve, and finally reaches the main stop-valve-box, which permits the absolute shutting off of all communications between the boilers and the engine. At this stop-valve-box begin the steam-pipes of the engine.

Cleaning the Boilers.

The boilers are easily cleaned: the interior of the tubular nest, by taking out the plugs of the connecting-boxes and applying the tube-scrapers and brushes; the exterior of the nest, by opening the front doors and using first the steam-cleaner, then the brush; the steam and feed-water collectors and the ejectors, by removing the plugs and scaling off with the usual tools.

Trial Trip.—Sea-water Test.

The necessity of the use of sea-water has been foreseen by M. Belleville, and has led to one of the peculiar improvements of the boilers, 1877 model.

The reasons why sea-water is harmless to the generators of this type are:

1. The arrangements for precipitating the salts that are insoluble at a high temperature in sea-water (sulphate of lime, &c.), and their blowing out while under way through the blow-off pipes.

2. The fact that the water level can be raised without any change in the state of the steam. The continuous carrying on by the steam of a large quantity of water into the upper tubes of the elements, prevents the deposit therein of any soluble salts. Any accumulation is carried by the water of the steam into the purifier and thence to the ejector.

3. The use of blow-out pipes, properly regulated, to prevent the density of the water in the generators from increasing above a certain limit, in order that there may be no fear of crystallization taking place in the lower tubes.

The trial began at 7 A. M. and lasted till 2 P. M. At 8 o'clock, saturation being over 4.5°, blowing out was commenced. To do this the blow-out cock was opened two or three times in quick succession in order to lower the apparent level by from three to four inches.

The same operation was repeated successively with the six generators. From 8 to 2 it was repeated twenty-four times, or every quarter of an hour on an average. No attempt was made to ascertain what effect this blowing out had on the consumption of coal, the main object being to ascertain whether the boilers would work in these conditions. An examination made two days later did not show any scale to speak of, either in the tubes or in the steam or feed-collectors.

Results of the Official Trials of the Engine of the "Voltigeur."

Nature of the Trial.	Natural draught. All the fires. Fires urged to their maximum.	Natural draught. All the fires. Moderate firing.	Natural draught. All the fires. Normal power.	Artificial draught. All the fires. Fires urged to their utmost.
Date of trial	April 27	April 27	April 30	May 29
Time of trial of consumption of fuel	4h 4m	4h 6m	6h 9m	4h 25m
Cut off from beginning of stroke of piston, middle cylinder	0.65	0.35	0.45	0.70
Opening of stop-valves of boilers	6/12	2/12	2/12	wide
Opening of throttle-valve of engine	wide	1/10	wide	wide
Opening of the valve	wide	1/20	wide	wide
Pressure in boilers, lbs. per sq. ft.	91.1	67.6	87.5	101.8
Pressure at the valve, lbs. per sq. ft.	58.7	57.9	60 4	59.8
Back pressure in the condenser, lbs. per sq. ft.	1.4	1.0	0.97	2.0
Temperature of feed-water	92° F	61° F	84° F	110° F
Heating of circulating water	17.5° F	14.4 F	18.5° F	18.0° F
Number of revolutions—				
Trial of speed	105.4	77.5	98.9	110.1
Trial of consumption	105.3	77.6	99.0	110.1
Developed power—				
Trial of speed (English H. P.)	894.5	357.3	725.6	985.6
Trial of consumpt'n (Eng. H. P.)	888.0	357.9	725.7	986.3
Coal consumed per hour—				
Per square foot of grate, lbs	26.7	8.8	18.2	32.8
Per horse-power, lbs	2.74	2.25	2.29	3.03
Weight of steam per H. P., lbs	20.05	20.07	19.02	...
Vaporization per pound of coal	7.31	8.92	8.30	...
Mean draught in feet	11.54	11.54	11.48	11.28
Difference of draughts	3.47	3.47	3.44	3.50
Immersed surface of midship frame square feet	224.88	224.88	223.5	217.9
Speed (knots ?)	11.85	8.99	11.35	12.48
Recoil (slip ?)	0.157	0.130	0.140	0.149
Utilization	3.37	3.47	3.46	3.40

Raising steam.—Steam was raised in a remarkably short time. Several trials were made with this object in view. By firing the six boilers at the same time steam was gotten up in fifteen minutes. The moment steam is up the engine is blown through. Eight minutes after there are 4 kg. pressure on the valve, and the engine may be turned over. This takes two minutes, and then the engine is ready to start. It takes therefore twenty-five minutes from the time of lighting the fires to start the engine. Fifteen minutes later it may be driven at a hundred revolutions a minute.

These experiments were made with the water-level at the base of the tubes, which is sufficient, requiring, with ordinary firing, 12 kg. of wood and 65 kg. of coal for each furnace. By sprinkling with oil three or four minutes could be gained.

Cleaning of fires.—The peculiar arrangements of the grate answer their purpose satisfactorily; the slag adhering only slightly to the bars, is easily detached. This part of the operation is rendered easy by the lower half-door; the troublesome part is that which necessitates the opening of the upper half-door, and exposes the fireman to the intense heat of the furnace for some considerable time. The cinders are thrown into the ash-pit and removed when cool. When it is proposed to clean all the fires, it is advisable, in order to preserve regularity in the pressure, to do one-half of a furnace at one time, taking each boiler in succession, and when this first half of the operation is ended, then to do the other halves.

Steam purifying.—The attachments for steam drying are ingeniously combined and always worked perfectly. When in the course of ordinary steaming it happened that the steam brought with it a little water in the main pipe, the general purifier stopped it, its automatic snifter turned it back into the cistern and the engine was not disturbed in the least. On starting the engine there never was anything beyond slight snappings, due to the condensing of steam in the cylinders insufficiently heated.

During the trial it required extreme and sudden changes in the rate (40 or 50 revolutions, for instance) to cause water to be carried over, and then in a very small quantity, which disappeared instantaneously. This saturation occurred mostly when the rate of steaming was decreased. In this respect the boilers of the Voltigeur possess remarkable qualities.

Purifying the feed-water.—The purifying of the feed-water is done perfectly; the use of lime-water in the course of experiments gave

ample proofs of this; and upon examination it was found that neither the tubes nor the feed-collectors presented any noticeable deposits. But the floors of the plane portions of the leading passages of the steam purifier had a layer of from 0.191 to 0.218 inch in thickness of adhesive black matter, being a mixture of calcareous salts and iron soaps.

In the ejector were found a large quantity of deposits of similar composition. One portion adhered to the partitions, and formed a funnel whose apex pointed down, reached a little below the orifice of the exterior extension of the snifting pipe. The balance of the deposits were in the form of concretions somewhat voluminous and compact, which filled the bottom of the ejector nearly up to the orifice of the blowing-out pipe.

Security.—An undeniable and very great advantage. The most serious accident that can befall the boilers of the Voltigeur is the bursting of a tube; this, however, is improbable, owing to the fusible plugs, which give timely warning of danger.

Quick pressure.—An extremely great advantage, and which, in the case of the Voltigeur, is demonstrated by the gain of nearly one hour over the time necessary to get an engine ready to work.

Relative lightness.—The weight of the boilers of the Voltigeur, excluding pipes, is 53.2 tons. Of the Chasseur, a similar vessel, 71.8 tons. The maximum production of steam per hour is: Voltigeur 8077 kilos ordinary firing, 9574 kilos forced firing; Chasseur 6593 kilos ordinary firing, 9571 kilos forced firing.

The tubes were perfectly clean in the interior; on the exterior appeared no signs of warping, but those tubes which were in direct contact with the flames were covered with a vitreous crisp coating easily removed, from 0.157 in. to 0.197 in. in thickness, apparently produced by drops of melted slags carried forward by the gases of combustion. It was specially when the fires were urged and with a high speed that these crusts were formed.

Sham repairs were made; they consisted in cutting the third tube of the front row of the second element of one of the boilers. The operation was performed in the manner already described, presented no difficulty, and took only about ten hours' time.

CONCLUSIONS.

The boilers are solidly built and well finished. Their peculiar apparatus for steam and feed-water purifying, as well as their self-

acting regulators of the state of the steam, are perfectly combined. All the attachments worked in a very satisfactory manner during the whole trial. While noting these advantages, the board does not pretend to cover the whole case of the boilers of the Voltigeur, but thinks that their working during ordinary steaming is a natural sequel to, and a necessary completion of, the trials. Many questions can be solved in that manner only. Attention must be drawn principally to the durability of the different attachments, to their possible breaking while in service, to their preservation when not in use, to the interior and exterior cleanings, to the working of the ejectors, to the different self-acting apparatus, and to the working and effects of protracted steaming with sea-water. The board cannot therefore deliver an absolute opinion upon the evaporative apparatus of the Voltigeur, but states emphatically that, in regard to security, lightness, rapidity of raising steam, facility of suddenly modifying the speed without risk of water being carried over, it presents great advantages, sufficient to counterbalance its drawbacks in the utilization of fuel, its complicated attachments, and the more arduous duty it involves.

Finally, the Board concludes by stating that the experiments made justify a careful examination of this style of boilers under the ordinary conditions of steaming, and that important advantages to the navy may result from the experiments made on board the Voltigeur.

NAVAL INSTITUTE, ANNAPOLIS, MD.

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RESCUE OF THE TRINITY'S CREW FROM HEARD'S ISLAND.

BY ENSIGN W. I. CHAMBERS, U. S. N.

While at anchor off Montevideo, Uruguay, November 10, 1881, the U. S. S. Marion, Commander Silas W. Terry, U. S. N., commanding, received telegraphic orders to prepare at once for sea. Amid the excitement of hurried preparations, written orders were received from the Admiral, then at Buenos Ayres with his flagship, the substance of which was to proceed to Heard's Island in search of the crew of the American barque Trinity, a whaler which had not been heard from in eighteen months. In order to show that "orders" are not always infallible, and as well to note a curious coincidence in the position of two widely separated islands, situated in the same latitude south, it may be interesting to mention that a simple substitution of the word west for east, in naming the longitude, falsely indicated the Marion's destination to be one of those small nameless islands near the west coast of Tierra del Fuego in the South Pacific. It was found, however, on inspecting a private chart, that a small group of islands, named McDonald or Heard's Islands, existed in the South Indian ocean, in the same relative position *east* longitude, which, upon inquiry by telegraph, proved to be the intended destination.

The want of certain supplies and charts necessitated touching at Cape Town, South Africa, where the Marion arrived after a passage of twenty-eight days; and, on the arrival of a steamer from England with charts, which had been telegraphed for from Montevideo, she sailed for Heard's Island, December 24th, accomplishing the passage of about 3000 miles, under sail, in eighteen days.

On the morning of January 12, 1882, the small barren group of rocks called McDonald Islands were passed, it being customary for navigators bound to Heard's Island to pick up this group first, on account of the bad weather and lowering clouds which conceal the island of our destination almost every day in the year. The cloud-capped and snow-covered shores of Heard's Island were dimly visible at 4 P. M., and our course was shaped for the southeastern extremity, upon rounding which an unexpected line of angry-looking breakers was seen ahead, extending about four miles seaward. Sail was quickly shortened, and as the ship's head was turned away from the land, a party of men were discovered faintly visible under the cliffs, waving a flag from the top of a low hut. It was just then, too, that the clouds parted and permitted a momentary glimpse of the majestic, hoary head of Mount Emperor William, after which a snow squall shut out the island entirely from view.

The ship then steamed cautiously around the end of a long low spit of land, the limits of which were well marked by the breakers before mentioned, and which forms an open bay in which she anchored at 9 P. M., rolling deeply to the heavy ground swell during the entire night.

It was then too late to attempt a landing through the surf, and about 10 P. M. a bonfire was discovered burning on shore, which was kept ablaze, as afterwards determined, by the application of forty barrels of sea elephant blubber. This bonfire rather assured us that our search had not been in vain, as anticipated, and accordingly when a boat was sent on shore next morning we were not surprised to learn that the Trinity's crew was drawn up in a group on the beach, almost speechless with joy at the prospect of rescue. Then occurred the transfer of the shipwrecked party from the island to the ship—a tedious task which was executed without accident, save that one of the boats had a hole stove into her bilge by contact with rocks on the beach.

The story of the Trinity, as related by her officers, is briefly as follows:

The American barque Trinity, 516 tons displacement, owned by Lawrence Bros., of New London, sailed from that port June 1, 1880, with a crew of sixteen men, including officers, and on June 23d arrived at the Cape de Verde Islands, where an addition of nineteen Portuguese negroes was made to the crew. On the 26th the Trinity bore away for the South Indian ocean, intent on obtaining at Heard's Island

a cargo of sea-elephant oil, a substitute for whale oil, which brings three or four cents less per gallon in the market. The vessel arrived at the Kerguelen Islands, better known to whalers as Desolation Land, September 4, 1880, where the last letters were deposited in a rude box or postoffice used by whalers and sealers; and after transferring the light spars, spare sails and some provisions to suitable shelter on shore, she sailed, September 28th, for Heard's Island, about 270 miles to the southward, where she arrived October 2d, and anchored in Corinthian bay. At that place four of the crew were landed with four months' provisions, after which the ship was taken to Spit bay, fifteen miles more to the southward, October 12th.

It was intended to keep the ship anchored near the best beach for landing until the empty oil casks and necessary provisions were rafted to the shore, then moor her about two miles further up at a safer anchorage. After which, leaving a few shipkeepers on board, the crew would have debarked to live in the wooden houses on shore, which had been brought there for that purpose on former voyages, hunt and kill the sea-elephants and try out oil enough to fill the casks that had been landed. Then, reloading and reëmbarking, they would have returned for the party left at Corinthian bay, thence to Desolation Land for the stores and to the Cape de Verdes to leave the Portuguese negroes, and thence, finally, home to New London.

Had this scheme been successful, instead of having been overcome by disaster, we would probably have never known anything of these secret and perilous enterprises for elephant oil and gain. However, while engaged in sending the casks on shore, a northerly gale sprang up, and the doomed ship, with two anchors down, seventy-five fathoms of chain on one and ninety fathoms on the other, was dragged about the bay at the caprice of the wind, which came in violent gusts, sometimes on one side of the mountain and sometimes on the other. Having been unable, at a favorable time, to lift the anchors, which "had fouled something on the bottom," the ship was at length driven towards a part of the beach from which a dangerous shoal projects, and, to prevent grounding at that place, the jib, topsails and foresail were hastily set as the cables were slipped, and, paying off before the wind, she skirted the edge of the dangerous shoal and was driven upon a steep beach, with the flying jibboom within twenty feet of the land, about 9 A. M., October 17, 1880.

The ship was fortunately thrown up so well that an expert swimmer was enabled to take a line on shore, by means of which one of the

boats was afterwards dragged back and forth, and the safe landing of all hands, together with some clothing and about three months' provisions, was accomplished by dark that night. Many articles capable of floating were thrown overboard to be drifted to the beach through the breakers.

Wet, cold and exhausted they slept through the night, expecting to land the boats, tools and remaining provisions next day; but while they slept the gale hauled to the westward, and when they awoke next morning the ship was nowhere to be seen, having been driven off the beach, together with many articles which had been left lying there, and it is presumed that she foundered in deep water.

They were then forced to live on this exposed spit of land in three light frame huts, the officers taking possession of one, the white sailors occupying another and the Portuguese the third, and for a while they fared very well. Every day, when the weather would permit, hunting parties started out to patrol the beaches for sea-elephants in order to get something to eat, and especially the wherewithal to make a fire, and they thus managed by incessant hunting to get enough to eat. At first the elephants were often killed for the hearts, flippers and tongues only, before they could get accustomed to the flesh, which is said to resemble in taste that of the porpoise.

When the provisions began to grow scarce and the ration of bread was reduced to a tablespoonful of crumbs per day, they suffered much, but one of the worst trials came when the tobacco gave out, June 14, 1881; and when the last of the ship's provisions, which had been scrupulously hoarded, was finally consumed, September 12, 1881, they were obliged to depend entirely on the resources of the island.

Elephant meat, sea-fowl, and particularly penguins, together with a species of wild cabbage known as the Kerguelen cabbage, became in turn, according to season, their means of subsistence. The latter probably had a great deal to do with keeping the men in a healthy state, though they often had to dig through three feet of snow to obtain this valuable wild vegetable, which, after being boiled in sea-water by way of seasoning, was eaten, as expressively stated, for "stuffing" only.

It speaks well for penguin eggs as a very nutritious article of diet, that some of the officers and men gained from fifteen to twenty pounds in weight during the period when eggs were plentiful. The penguins, though easily caught at first, soon grew so wild and scarce

that it became very difficult and tiresome to catch them, as they propelled themselves over the ice and snow with a sliding, jumping motion, and there were days that, despite desperate hunting, only one or two penguins represented the entire catch of the various parties. It is easy to imagine how despairingly hungry the poor fellows must have felt even after partaking of the thirtieth portion of a penguin, the allowance for each.

It is not surprising that among the men there was occasional quarrelling. One stabbing affray occurred, but it was fortunately unattended with serious results. Sometimes as many as ten men were off duty at one time from weakness or sickness, produced generally by long enforced abstinence from food. There were also notorious shirks, who, under plea of sickness, hung around the huts all day, especially when the weather was unusually bad. Had not discipline been maintained, more than half of the men would have perished through their own recklessness, as some of them with that short-sightedness which comes from suffering and a weak will, were inclined when meat was more plentiful than usual, to surfeit themselves and not provide for long days ahead. But Captain Williams, who had before this been wrecked for a short time on this same island, understood the requirements of the situation, and to his credit maintained his authority throughout.

Clothing became worn out and scarce, and all sorts of ingenious devices were resorted to to make it last; for instance, tattered shirts and trowsers were backed by heavy canvas, and boots were shod with pieces of broken saws, but that of the poor Portuguese was so scanty that some of them were obliged to go stockingless and even barefooted at times.

It was thought that the month of January would bring more moderate and warmer weather, but instead, heavy gales with snow squalls were of daily occurrence, though the season was midsummer. In fact there were but three or four pleasant days during the three summer months. The huts were made as warm as possible by being covered with tussock. Hunting was kept up unceasingly, but days would pass without a sign of the animals which, even when sighted on the beach, were not easily secured, as it required the cover of darkness to surprise them, and the only weapons possessed by the hunters were lances.

During February, 1881, the bad weather continued with gales of wind and snow squalls nearly every day. During March the food

supply ran alarmingly short, but on the 24th of that month, when the situation was desperate, one of the parties succeeded in killing three sea-elephants, the flesh of which "kept the wolf from the door" for several days. Whenever a capture was made the hunters pulled the meat and blubber through the snow on rudely constructed sleds to the huts. During winter the snow lay three or four feet deep down to the water's edge. During April and May penguins frequented the island in large numbers. June, July and August were cold, dreary, cheerless months, and some days, with all hands hunting for food, the men would return weary and jaded without having secured anything to eat.

October 17, 1881, the first anniversary of the wreck, was a gloomy day, there being a strong gale from NNW. with snow and rain, during which the barometer fell to 28.45. There was not a mouthful to eat, and the men were in very low spirits indeed. Twelve months on the island and no sail had been descried! Worse still, on the previous day one of the men who had become demented by the hardships endured, had reported two sails in sight about two miles up the beach, to reach which all hands had started through the blinding snow then falling, only to find that the sails reported were two icebergs drifting past the island. Most of the poor sailors were by this time a walking mass of rags and many of their shoes were worn out, in consequence of the rough usage which their searches for food entailed.

They were enabled to exist, however, on the desolate island for fifteen months with the loss of but two men. George Watson, carpenter, and Bernard Kelley, seaman, who had been out during a storm on January 30, 1881, in search of penguins, were unable, through exhaustion, to return to the huts, and their frozen bodies were found next day, near one of the glaciers, with smiling upturned faces, cold in death. The bodies could not be removed until February 2d, when they were transferred to the beach, placed in one box and buried.

The four men left at Corinthian Bay fared better than their shipmates, but after remaining fourteen months without knowledge of the ship, became uneasy, and as land communication between the two harbors was impossible because of the bold shore and rugged glaciers which reach to the water's edge on all sides, they built a small scow 7½ feet long by 3½ feet wide, using the tools that had been left with them and some of the boards of which their house was made. Two of them, Henry Story, boatsteerer, and James Gill, seaman, started down to Spit Bay in this rude box, and, although the weather had

been unusually fine for several days, these brave fellows were twenty hours paddling their frail craft only fifteen miles.

Story took with him the tools necessary to build a better boat from the timber in the houses at Spit Bay, and in this way opened a safer means of communication between the two places. In the other boat, built like a dory, he visited Red Island, a detached rock, situated about five miles from Corinthian Bay, and there discovered an old whale-boat which needed a few repairs to make it serviceable, and it was intended to repair and utilize this boat later on for the purpose of visiting different parts of the island in search of food. However, bad weather postponed the execution of this design, until January 12, 1882, when the Marion arrived and gladdened their hearts with the sight of the "Stars and Stripes" which was hoisted in answer to their signal of distress.

About 4 P. M., January 13th, the Marion, under steam, started for Corinthian Bay against a gale of wind which so impeded her progress that it was too late when she arrived there to take the three remaining men on board that night. By 8 A. M. the next day all were safely on board, and forgetting past hardships in present joy, were taking a glad farewell of their late hoary-headed and relentless jailer, who, wrapped in a mantle of snow squalls, was soon hid from view.

The Marion then proceeded to the Kerguelen Islands, where, after anchoring for one night in Greenland Harbor, she was blown off shore by a northerly gale, thus preventing a visit to Betsy Cove where the Trinity's stores were stowed; and without further delay the course was shaped for Cape Town, where she arrived February 20, 1882, and where the State Department became responsible for the further care of the unfortunate whalers through the person of the U. S. Consul at that place.

Her arrival there was timely, inasmuch as she was able to render much needed assistance to the large iron English ship Poonah, which had recently been stranded on the Blauberg shore of Table Bay, and which was in constant danger of going to pieces should a northwest wind spring up.

Heard's Island—Retrospective Description.

Heard's Island, situated in latitude 53° 20′ south, and longitude 73° 10′ east of Greenwich, is about thirty miles in length and fifteen miles in width, extending in a direction about NNW. and SSE.

It was first discovered by an American captain named Heard during a voyage to the East Indies in 1853, who stated that he believed it to be a floating island, as he had sailed over its position repeatedly on former voyages. The floating island theory is destroyed by the fact that it contains an active volcano, and the inaccuracy of Captain Heard's navigation indisputably proven by various landmarks about the island which give evidence of former glacial action dating back certainly beyond the period of that worthy navigator's birth.

It is related that, at a later date, Captain Darwin Rogers in the old American whaling ship Corinthian was one day trying out elephant oil, in the bay named after that ship, when another ship hove in sight with the English Jack flying, her captain intent on taking possession of the island in the name of Queen Victoria. A sight of the "Stars and Stripes" thwarted this ambition, and a glance at the Portuguese negroes, dirty with the work of trying out, caused the jealous and disappointed Englishman facetiously to inquire whether they were specimens of free-born American citizens or natives of the island.

Rogers' Head at the entrance to Corinthian Bay is a remarkable headland, resembling at once a sphynx and a fortification. The marks on this natural parapet form such a perfect imitation of masonry that were it not for a knowledge to the contrary, one would imagine the harbor to be fortified; and the delusion is greatly enhanced by a very conspicuous line of red clay which apparently marks a cemented junction of the masonry with the slope of the hill upon which it rests.

This natural fort evidently once contained a powerful magazine of nature's combustibles, as may be inferred from the extinct crater which lies within its enclosure. On the left side of the entrance to the bay, which is about a mile wide, rests a majestic glacier, whose hard rough face, rising perpendicularly from the water about eighty feet, frowns coldly upon the stolid sphynx opposite; her head, rising about six hundred feet, seeming to brood in sullen silence over the memory of a rudeness to which she had been subjected by a former glacier, which had savagely brushed against her, scorning the battery at her back, and which had cut and scarred her face so much that many parallel curved lines or scars are yet left to remind her and posterity how the irresistible monster broke the ties that bound him to the narrow limits of Heard's Island and floated away to warmer climes.

At the southern extremity of the island a low narrow spit of land extends out to seaward about four miles. As the currents about the island almost invariably trend on either side along the shore towards

this spit, it is easy to conceive that it has been formed and constantly grows at the junction of these currents by deposits of lava and other *detritus* brought down from different parts of the island. Its shallow extremity is changeable in position according to the duration and violence of certain winds, and at times it has been noticed to extend in a direction at right angles to that of the main arm.

During the fifteen months of their confinement on the island the shipwrecked people seldom saw the summit of Mount Emperor William, which is estimated to be about 6000 feet high, but on November 27, 1881, the weather was clear enough to see what appeared to be smoke issuing from the mountain top in three columns. Again, on July 2d and 4th of 1881, three columns of smoke and one of fire were plainly visible. Frequent puffs of hot air were felt when the wind came from the direction of the mountain, and pools of water, occasionally found on the glaciers, were strongly impregnated with sulphur. It is probable that the volcanic nature of the island has something to do with the rapid change in the magnetic variation of the locality, which was found to differ by about 7° from that determined by H. M. S. Challenger during her memorable cruise.

However interesting the island may be to the student of natural history, it is not surprising that under the trying circumstances of their situation the Trinity's unfortunate men were unable to appreciate its interesting features.

In conclusion it may be well to add that from the appearances of the cloud formations observed to the southward of Heard's Island, and from observations on the flight of birds, it is believed that another uncharted island lies in that direction, from sixty to one hundred miles distant. True it is that the seals, many sea-elephants and penguins have left Heard's Island to rear their young elsewhere, and it is said that a certain sealing captain has discovered an island in this vicinity, the position of which, in the interest of the trade, remains a secret, by which he is able to realize large and easily obtained cargoes of seal skin.

PROFESSIONAL NOTES.

COLLISIONS AT SEA.

An article by Don Jose de Carranja, Spanish Navy, translated by Ensign Chas. C. Rogers, U. S. N., of the Office of Naval Intelligence, treats at length of recent improvements in nautical science by which the risk of collisions might be lessened. That naval discipline and the present rules of the road are insufficient was conclusively proved by the collisions resulting in the loss of the Vanguard and the Grosser Kurfurst. Attention is called to the necessity of using mechanical means for transmitting orders, avoiding risk of their being misunderstood; of utilizing steam or hydraulic power for steering, and particularly to the utility of turning trials of ships under all possible circumstances of wind, weather and speed, that the officers may become fully conversant with the qualities of their vessels. The latter part of the article is devoted to a consideration of different proposed improvements of the side lights, by which not only the position, but also the course steered, may be indicated with certainty at night, and this merits particular attention. Señor de Carranza says:

"In 1878, Messrs. Francis & Co., of London, inventors of the *Electric Ship Steering Indicating Lamp*, proposed an additional system of side lights to the present one; from their descriptions we extract the following:

In the *Addenda* presented to the Woolwich Board, during the investigation of the loss of the *Princess Alice*, is expressed the following idea, which we deem worthy of adoption: 'We can never sufficiently impress upon the Board of Trade and Lords of the Admiralty why they should take into consideration the proposition of Captain Fitzgerald that ships carry two lights on each side; then by the opening and closing of the lights would be indicated the side towards which the ships steer in their approach.'

This idea, included in the Francis plan, consists in placing vertically and near the usual side lights other lights with screens of red and green glass. Between the helm and these additional lights copper wires and a small battery are placed, disposed in such a way that when the helm is amidships bright white lights are shown; but on putting it to port, for example, an alteration in the direction of the electric current raises the red screens or lenses, and both additional lights are seen red, showing that the helm has been put to port, turning the bow to starboard. In the same way the green lights are shown when the helm is put to starboard, turning the bow to port.

The lights and the helm, as already said, are connected by insulated copper wires, and the battery used supplies a constant current, and occupies, in fact, a

very small space between decks. The battery requires little attention, and the lights the same as either of the others.

The copper wires and the battery are insulated, and the lights, when in place, form the proper connections without any one being permanently stationed at them. Another peculiarity of the Francis Light is that the battery used is nearly always inactive, and at no time is a break through weakness to be feared. So little is the battery required that it is not absolutely necessary, since the sea itself can form a battery so well known, called the *salt water* battery, which is constant.

In addition to the side lights, the masthead and stern lights can be used. Then these last will indicate to ships approaching each other with great speed the direction in which the vessel ahead is steering.

In fact, without altering the plan, the lights required can be worked all at the same time, and by using simple telegraphic instruments there could not exist the possibility of a mistake, which is the fruitful cause of so many disasters.

Nor ought the loss of the English ironclad *Vanguard* to be forgotten, which, without doubt, with the lights we add, would have been able to show to the *Iron Duke* the direction in which she was steering, though in a dense fog. Messrs. Francis & Co. say that in consequence of the respectability of those who have testified to the importance of the light and the plan with which we are occupied, the British Parliament should institute a modification of the international system of side lights, requiring ships to carry a light working by electricity and indicating the course or helm. These gentlemen will exhibit to the London public, at the Eagle Telegraph Factory in Hatton Garden, their lamp or light working on models.

However, with the commendations and satisfactory results for which Messrs. Francis & Co. hoped, we are informed that this plan was submitted to the concurrence of maritime nations with the idea of altering the present system. But in spite of the fact that in all the many pamphlets and memorials that have been written, the existing plan is regarded as inadequate for the needs of the rapid steamers of this day, years pass and mishaps increase, and Great Britain owning the largest navy and mercantile marine in the world as well as the greatest wealth off the sea, will not take the initiative in meliorating the existing state of affairs, as humanity and interests certainly require.

In the Italian *Rivista Marittima* (Maritime Review) for July and August of 1882 is a description of the system of side lights proposed by Captain E. de Littrow, of the Imperial Austro-Hungarian Fleet, from which we extract the following:

'The principal cause of collisions at night lies in the defective system of lights, which provides when under way one green light on the starboard, and one red light on the port side.

With only one light, the change of a ship's course is not made sufficiently apparent to the eye, while with two lights of the same color on each side any turn, however small, to port or starboard to avoid collision can be seen at once. The distance between the side lights of the same color varies from 8 to 12 metres as the ship's size admits, and if made greater than this, so much the better will it be for the purpose intended.

The after light should not be visible except on the side through an arc of the horizon of 50° at most.

A ship with double lights seen end on, will show only *one* red and *one* green light, as the bow lights shut in the after ones. Whatever be the change of course, to port or starboard, it will be shown immediately by the appearance of the after light. When *b* sees the second red light he knows that *a* is changing his course to starboard, *a*'s red lights becoming gradually more distinct until seen with full brilliancy.

The after light should not be seen except from the *side* of the ship, and for this reason should be darkened on the forward side.

To avoid collisions, the relative movements of the ships must be known. This object is obtained with this plan of lighting.

Should either ship steer the wrong way, it will be detected at once, thus enabling the other vessel to avoid collision.

Take another example: *a* and *b* crossing so as to involve collision; *b* sees two green lights and understands that he should immediately port his helm and exhibit his two green lights to *a*. In this case no danger will be incurred, for *a* and *b* show two lights of the same color.

Experiments made on small ships with this modified system of lights have been attended with complete success, the results corresponding perfectly with the design. In the Austrian squadron on the coast of Dalmatia experiments are making on the larger ships. The greater cost of the light should not be considered, since it is used to more effectually avoid disasters and save human lives. Even in the present system of one colored light on each side, efforts are making to discover some berth or cabin light which can be exhibited to take the place of a second side light and show the tack or course on which a ship is steering. This want exists in every navy, and is sufficient to justify the adoption of a second side light.'

Mr. Littrow says nothing of the white stern light that is so necessary to a vessel stopping or sailing with less speed than the one following her on the same course.

We continue our subject with an extract on the system of lights designed by D. Jose Ricart Giralt, Professor at the Naval School, Barcelona, a description of which is published in the *Rivista Marittima* of this month:

'It is twenty years since all navies adopted the present regulation regarding side lights for the prevention of collisions, which establishes one green light to starboard, one red light to port, and one white light at the masthead of steamers, a system which without any doubt has proved of immense value, saving many lives and much material.

But for the very reason that the navy during these twenty years has undergone and is now passing through a radical change, with great increase in the number, dimensions and speed of steamers, we think that the present regulation is inadequate, and for that reason it is necessary to change it as soon as possible.

Now, on account of high speed the signal which a ship makes at night for the prevention of a collision should be a *speaking* one, in order to indicate with

certainty and at the moment the movement which the two ships ought to make without danger of doubt or loss of time.

The plan of Captain Littrow (already mentioned) printed in the *Rivista Marittima* of last July and August is a step in favor of our idea of a *speaking* signal; but, in my judgment, is incomplete, because like all modern systems it leaves the stern unlighted, as if there were no ships that move with greater speed than others. Besides, in the system mentioned, the two stern lights are given a range covering an arc of the horizon comprised between two perpendiculars to the keel, which causes the serious objection that a ship must describe a large arc before seeing the two green or red lights on the same side; finally, I do not think it advantageous for the two side lights to be of the same color, because in very large ships they would look, at a distance, like the lights of two different ships.

If the system be adopted, in my opinion the three following conditions should be fulfilled:

1. That the ship's lights be visible over the whole horizon.

2. That the lights of a ship, seen from any point, indicate the direction in which she steers.

3. That while the bow is passing through a small arc, the evolution that the ship is making be shown by the varying aspect of the lights visible.

In my opinion the plan of Captain Littrow is very far from fulfilling the conditions enunciated, and, for this reason, I am induced to present the following plan:

Every sailing vessel shall, when under way, carry the following lights:

On the starboard bow, a green light, so constructed as to show a uniform and unbroken light over an arc of the horizon of 115°—say ten (10) points of the compass, and so fixed as to throw the light from right ahead to 25°—say two points—abaft the beam on the starboard side. On the port bow, a red light, so constructed and fixed that it will fulfil the same conditions on the port side that the green light does on the starboard.

In the wing or on the quarters, on the starboard and port sides respectively, a white light, so constructed as to show a uniform and unbroken light over an arc of the horizon of 115°—say ten (10) points of the compass—and so fixed as to throw the light from right astern to 25°—say two points—forward of the beam on the starboard and port sides respectively.

Steamers, besides the lights required for sailing ships, should carry a white light at the foremost head, as at present.

Let us see if this system satisfies all the conditions that may arise:

1st Case. Two vessels meeting end on or nearly end on, so as to involve risk of collision, both ships should steer to port (*i. e.* the helms of both should be put to starboard,) so that each may pass on the starboard side of the other.'

(This is contrary to present regulations and its necessity is not shown.)

'2d Case. A ship which is being overtaken by another shall keep her course; and the one astern should alter her course to pass to leeward of the sailing ship which is ahead.

3d Case. Two ships crossing at right angles, so as to involve risk of collision. Both ships should steer to port until the ship whose red light is visible loses sight of the other's green light, and sees only the white light aft.'*

(This is contrary to present regulations and the necessity of a change is not shown.)

'4th Case. Two ships crossing at an oblique angle; if the angle be acute, both ships should steer to port until the one whose red light is visible loses sight of the other's green light, and the latter loses sight of the white light of the former.'

(Article 16, present Regulations, reads: "If two ships under steam are crossing so as to involve risk of collision, the ship which has the other on her own starboard side shall keep out of the way of the other." This manœuvre is contrary to the present rule, and the reason for changing it is not given.)

M. P. Prompt, in his pamphlet, says "That if the angle of crossing be acute, both ships should keep away; that is each should steer towards the side on which she does not see the other; the one that sees the other to starboard should slacken her speed, and give the way." We prefer these rules to those of Mr. Ricart).

If the angle formed by the courses be obtuse, both ships should steer to port until each sees the other's white light (aft).

(M. Prompt says: "When two ships are crossing at an obtuse angle, so as to involve risk of collision, both should steer to starboard." We prefer this rule to that of Mr. Ricart.)

'5th Case. Two ships steering on parallel courses, but in opposite directions. Each keeps on her course until she loses sight of the other's after white light.

6th Case. Two ships steering on parallel courses. Each keeps on her course, but if the one showing her red light disappears it will indicate that she has steered to port.'

I repeat that this system seems to me to fill the blank which exists in that of Captain Littrow, because, besides lighting the stern, the white lights are so fixed that they are seen at the instant the manœuvre begins; in other words, the system is a *talking* one, which is what mariners need. Our opinion about the rules that Mr. Ricart gives is expressed in parenthesis; but comparing his system with that of Captain Littrow, we think it has the advantage in placing a light at the ship's stern, which, among other plans, Mr. Francis suggested in 1878 and M. Prompt establishes in his pamphlet, though Mr. Ricart Giralt does not know it.

In comparing the descriptions of these schemes we meet with a discrepancy in both, since they say that the additional lights reveal immediately the least change of course in ships approaching. This is not the case.

Captain Littrow gives to the additional lights a range which covers an arc of only 50° of the horizon (on the sides), that is, until the ship has passed the danger of the bow or side, the additional light is useless.

Mr. Ricart, in his turn, says that the system should show with certainty

*Such a radical change is impracticable; besides there can be no necessity for it.—TRANS.

and immediately the movement which the approaching ship is executing, without danger of doubt or loss of time. The additional lights of Mr. Ricart cover an arc of 114° of the horizon, or from right astern to two points forward of the beam, that is, that the ship in her approach passes through the risk of collision from the bow until two points off the beam.

The movements proposed by Mr. Ricart are analogous to those prescribed in our General Fleet Orders before the international rules were adopted. They conflict with those established by the latter system, and without showing the advantages in the change we think their adoption should be continued in all navies from this date.

The pamphlet entitled *Tactiques des abordages en mer et moyens de les prevenir* (Tactics of Collisions at Sea and Rules for Preventing them), published by Lieutenant M. P. Prompt, of the French Navy, is very interesting. It suggests that the lights be extended to the quarters and stern. From the study of these plans and of others in which the open light is discussed we infer that the idea of Captain Fitzgerald in 1878 was the same as that which Captain Littrow proposes. It seems more complete for practice, having the light aft, as many sailors have suggested and Lieutenant M. P. Prompt recommends in his pamphlet.

The system of Messrs. Francis, though we have seen it work satisfactorily, seems liable to confusion; but if through conclusive experiments it should meet with confidence, we would be inclined to accept only that part in which the white light forward shall be used to show, with a green or red lens, the direction in which the ship steers to avoid collision.

We are inclined more to the white lights than to the colored, for inasmuch as white lights are used in the flash signals of Captain Colomb, R. N., the red and green lights for squadron signals have disappeared. And we think that the colored side light should not be used, since its intensity is one-fifth that of the natural or white light.

What risk is there if the additional lights are visible from right astern to the range of the side lights if the result be to reveal immediately when the ship steers to starboard or port? We know of none, and for that reason we would suggest that wing lights cover the range astern and on the sides, thus improving the systems of Messrs. Littrow and Ricart.

If the lights were all white, both those on the sides and at the masthead could be made to emit short flashes on steering to starboard and long ones when turning to port. These signals could be used especially with ships close aboard and crossing each other's track. Sailing ships would carry, of course, only the side lights.

This subject merits greater consideration and study, for international interests require the solution of a system that will lessen the repeated collisions due to the daily increase in the number and speed of steamers.

The better English steamers from Liverpool to New York and Australia maintain a regular speed of fifteen or sixteen knots per hour, and when one of these vessels sights a colored light at night its distance in clear weather would be—say—two miles, a distance which they would pass over in four minutes, and during that time, if the courses cross each other, they should steer so as to avoid a terrible collision."

	1. Gramme. 1 lamp.	2. ‡Jurgensen Serrin lamp.	3. Maxim. 1 lamp.	4. Siemens. 1 lamp.	5. Siemens. 2 lamps.	6. Bürgin. 3 lamps.	7. *Gramme. 3 lamps.	8. Gramme. 5 lamps.	9. Siemens. 5 lamps.	10. Weston. 10 lamps.	11. Brush. 16 lamps.	12. Brush. 40 lamps.	13. Brush. 38 lamps.
Measurements of Power.	Hand lamp					Crompton.							
1. Revolutions of generator per minute	475	800	1017	737	1330	1535	1695	1496	826	1003	770	700	705
2. Horse power applied to generator	15.91	21.38	4.01	4.38	5.24	5.25	8.00	7.89	4.98	12.83	13.21	29.55	32.91
Electrical Measurements.													
3. Resistance of generator in ohms	0.33	0.45	0.70	0.66	1.68	2.80	†0.52	4.57	7.05	1.88	10.55	22.38	22.38
4. Resistance of mains (without lamps)	0.10	0.82	0.25	0.12	0.13	1.50	1.25	0.62	4.50	1.50	2.56	2.60	7.90
6. Current in amperes	109.2	90.0	33.0	35.0	26.2	18.5	19.0	15.3	10.0	23.0	10.0	9.5	9.5
7. Fall of potential at each lamp, in volts	53.0	58.0	53.0	53.0	44.5	41.0	53.0	49.8	47.4	32.0	44.3	44.3	44.3
Electrical Calculations.													
8. Energy appearing in generator and mains in H. P.	6.87	13.80	1.39	1.27	1.67	1.97	0.86	1.63	1.55	2.40	1.77	3.03	3.67
9. Energy appearing in one lamp in H. P.	7.76	6.87	2.28	2.49	1.57	1.02	1.35	1.03	.63	.99	.59	.56	.56
10. Energy appearing in all lamps in H. P.	7.76	6.87	2.28	2.49	3.14	3.04	4.05	5.13	3.16	9.86	9.47	21.58	20.51
11. Total electrical energy in H. P.	14.64	20.67	3.67	3.76	4.81	5.01	4.91	6.76	4.70	12.26	11.23	24.61	24.18
12. Mean electromotive force	102	172	84	80	136	203	193	328	353	398	840	2009	1971
Photometric Measurements.													
13. Diameter of carbons, in millimetres	20	23	12	18	14	13	14	12	10	9&10	11	11	11
14. Horizontal illuminating power in candles, each lamp	9044	5767	2337	1995	1349	475	1473	1064	637	874	352	§599	§599
15. Maximum illuminating power in " " "	18620		4418	7648	5102	2156	3392	1748	684	1463	722	741	741
16. Mean spherical illuminating power in " " "	9177	6536	2271	2907	1947	779	1586	969	494	807	361	371	371
17. Total mean spherical " in candles, all lamps	9177	6536	2271	2907	3895	2337	4758	4845	2470	8070	5776	14840	14099
Results.													
18. Gross efficiency. Percentage of electrical energy to power applied	92	97	91	86	92	95	62	86	94	95	85	83	73
19. Net efficiency. Percentage of energy in arcs to power applied	43	32	57	57	60	58	51	65	63	77	72	73	62
20. Percentage of total electrical energy appearing in arcs	53	33	62	66	65	61	83	76	67	80	84	87	85
21. Candles per H. P. applied	576	306	565	663	743	445	595	614	496	629	437	502	427
22. Candles per H. P. of electrical energy	627	316	618	773	811	466	967	717	526	659	514	603	583
23. Candles per H. P. of energy in arcs	1240	590	1097	1169	1245	769	1171	945	783	818	669	690	687
24. Candles per ampere	84.1	72.6	68.8	83.1	74.3	42.1	83.5	63.3	49.4	35.1	36.1	39.1	39.1
Additional Calculations.													
25. Total resistance of circuit	.93	1.91	2.55	2.29	5.19	10.97	10.16	21.44	35.30	17.30	84.00	211.47	207.47
26. Total external resistance (mains and lamps)	.60	1.46	1.85	1.63	3.51	8.17	9.64	16.87	28.25	15.42	73.45	189.09	185.09
27. Ratio of external to total resistance	.65	.76	.73	.71	.68	.74	†.95	.79	.80	.89	.87	.89	.89

*Afterwards found to be a defective machine.

†Self-exciting machine, with two armature coils, one in main circuit and the other in circuit of the field coils. The latter is not included in the internal resistance of the generator.

‡Tested under abnormal conditions.

§Evidently an error, as is seen by a comparison with the figures obtained with the 16 light machine in line 16. In line 14 the tables give 37 carcels for the 16 light, and 63 carcels for the 40 light. This is probably an inversion and is designed for 36 carcels or 342 candles, which agrees well with the ratio in line 16.

TESTS OF DYNAMO MACHINES AT PARIS EXHIBITION, 1881.

Among other causes preventing an exact comparison of dynamo machines is the fact that tests are conducted differently by various persons both as to method and instruments employed, and it becomes difficult to institute a correct comparison between results obtained in different trials. Of late greater uniformity has come to exist, and the data obtained agree more closely. The Paris Exhibition presented the best opportunity of comparing the different types of dynamo machines that had been offered up to that time, and a committee composed of well-known experts was appointed for the purpose of making exact tests. The accompanying table exhibits the results attained, and as the measurements were made by the same persons, and as nearly as practicable under the same conditions, they afford the best means yet published of deciding on the *relative* merits of the different machines. It is worthy of notice that the measurements of light are lower than those generally obtained, but if all are lower the *relative* merits are unaffected. The table is copied from the New York Electrician for February, but the French measurements of power and light are recalculated, and expressed in English horse power and candles to facilitate comparison with other measurements. One or two obvious errors have been corrected and attention called to others in which the amount of error is uncertain.

BIBLIOGRAPHIC NOTICES.

ANNALEN DER HYDROGRAPHIE UND MARITIMEN METEOROLOGIE.

No. 12, 1882. The four voyages of the Dutch ship Willem Barents to Barents sea in 1878–1881. The thunderstorm of Aug. 9, 1881. Oceanographic observations in the South Atlantic Ocean from July to Sept. 1882. Oceanographic observations in the Gulf Stream from April to July, 1882. Entries in the meteorological journals of the German observatories for Aug. 1882. Comparison of the weather of North America and Central Europe for Sept. 1882. Cruise report of ships of the Imperial navy for 1882.

No. 1, 1883. The physical geography and meteorology of the Cape of Good Hope. Deep sea soundings of Siemens' steamer Faraday. The hurricane in the Indian Ocean in May, 1881. Rules for the handling of chronometers (from Proc. U. S. Naval Institute). Entries in the meteorological journals of the German observatories. Thursday Island. Comparison of the weather of North America and Central Europe for Oct. 1882. Brief hydrographic notices.

PROCEEDINGS AMERICAN PHILOSOPHICAL SOCIETY.

Vol. XX, No. 110. A Manual for the Use of Students in Egyptology. By Commo. Edward Y. McCauley, U. S. N.

No. 111. The inclination of the apparent to the true horizon and the errors rising thereof in transit, altitude and azimuth observations. The aurora of April 16–17, 1882. Photodynamic notes.

No. 112. Radiant heat an exception to the second law of thermodynamics. Photodynamic notes.

TRANSACTIONS AMERICAN SOCIETY OF CIVIL ENGINEERS.

October, 1882. Preservation of Timber.

The society has appointed a committee to investigate this important question, and the present number is devoted to the preliminary report of the committee and to the consideration of papers by several members upon the merits of certain special methods, and to discussion upon the same.

November. Rapid Methods in Topographical Surveying.

December. Discussion of Paper on Rapid Methods in Topographical Surveying. Weights and Measures. Care and Maintenance of Iron Bridges.

In discussing this last paper Theodore Cooper considers at length the subject of the corrosion of iron, and sets forth the conditions under which the corrosion goes on most rapidly, and the means by which it may be arrested.

A Peculiar Phase of Metallic Behavior.

In Sept. 1881, an invoice of so-called gilding metal, presumably an alloy of copper and zinc, was received at the Frankford Arsenal for the manufacture of cartridge cases. Owing to the uniform success of his output, the contractor who supplied this metal had come to be regarded as the maker of standard sheet cartridge copper. This particular delivery was subjected to the usual severe treatment, met every demand, underwent every proof in the customary satisfactory manner, but failed in the firing test, of course a fatal defect. The contractor was notified and saw convincing evidence of the failure, but he stated positively that this especial lot of metal had been treated in precisely the same manner as the accepted invoice immediately preceding it, and that he was unable to account for its shortcomings. Capt. O. E. Michaelis, Ord. Corps, U. S. A., describes all the tests applied and illustrates his descriptions with diagrams and plates. He concludes: "From my recent experience with this metal, I believe it, in a measure, confirms the theory of refreshment first expounded by a member of the society; it appears to be in better condition now than at the time of its rejection seven months ago. No adequate reason can be assigned for the final failure of the metal, that so successfully passed through all the exhaustive tests established by extended experience and profound theory. It simply 'broke down' in an inexplicable, unexpected manner. Though but a straw, this failure leads my mind to harbor the heretical misgivings that preliminary static tests of materials furnish data useful only in the solution of questions in the calculus of probabilities. Nothing positive can be drawn from their consideration." Discussing this paper, Dr. Egleston said cartridge metal is not of constant composition, being sometimes of brass with a large per cent. of zinc, and sometimes copper with just zinc enough to make the copper draw with certainty. The latter passes under the name of gilding metal. Failures of punched and spun brass are quite common, and manufacturers allow for a certain percentage in their specifications. The sources of failure are numerous with these alloys. First, copper is a very delicate metal, and a very small percentage either of its own oxide or of other impurities will ruin it for commercial purposes. In the hundreds of samples of commercial copper which he had examined he had not found, until within two years, since the perfection of certain processes of refining, copper that could even be called commercially pure. It generally contains, besides oxygen, small amounts of lead, zinc, cobalt and nickel. This is true to a great extent of the coppers produced in the great Appalachian range, and to a less extent of those of Lake Superior, which have always been considered, until copper began to be produced from Arizona, as the best copper in the world. This copper may be spoiled in the refining or in the melting by which brass is to be made. It may be spoiled by oxidation in the melting; by over-heating or under-heating in the annealing; or by over-compression in the rolling. Over-compression or overheating causes the metals to "flow," and they separate. He has sampled as many as 500,000 cartridges in a factory by firing, and found that many could only be fired once, a few would fail on the second firing, still fewer would fail at the third, and occasionally cartridges could be found in the same batch of metal which would fire 150 times. In every case the failure was due to the same cause, and after examining hundreds of them he became satisfied that this cause was either too great compression or too much heat; this being true even in those samples which contained a minimum quantity of the volatile metal. He has separated from many of these metals volumes of gas which were five, sometimes ten, times the bulk of the metal, and hopes at some future time to analyze this gas. This phenomenon of the separation of gas always occurs in those metals which have been most compressed, and it would appear as if the brittleness was owing, in a great many cases, to the expansive force of the gas at high pressure, which is a force within the metal tending to help any force applied from without which would deteriorate it.

ENGINEER.

JANUARY 12, 1883. The Loss of the City of Brussels.

The first point worthy of notice is that the case of the ship, after she began to leak, was hopeless. But nevertheless, unaided by any assistance from the crew, she did not founder for about twenty minutes. It is clear then some obstacle prevented the water finding its way through the whole ship at once. The ship was however divided into seven water-tight compartments, and the reason assigned for her foundering was that the "Kirby Hall" struck her at the end of a bulkhead and so knocked two compartments into one. This, however, is to a great extent pure conjecture; and even if it is true, then the circumstance furnishes another argument in favor of so constructing bulkheads that two compartments cannot be knocked into one. But assuming the bulkhead was what it was—insufficient beyond a certain point—it is easy to see that had very moderate pumping power been brought into play, the ship could have been kept afloat. The utmost quantity of water to be dealt with was about 2000 tons lifted say, 20 feet in 20 minutes; this represents 448,000 foot pounds per minute or 135 horse power; or making large allowance for waste, an engine of 250 horse power, properly used, would have kept the water pumped out as fast as it came in. In most of the great passenger steamers recently built, immense pumping power has been provided; but the City of Brussels was thirteen years old and sufficient importance was not then attached to pumps. It is a noteworthy fact that bulkheads as usually fitted are absolutely worthless. In this statement the collision bulkheads are excepted, for they alone are invariably well made, well designed, and therefore efficient.

Copley's Compound Launch Engine. Nabholtz's Improved Frictional Rivetter.

This machine has put in, in one hour, 480 ¾-in. rivets into plain girders, the work being already drifted and prepared, so as to have no other impediments but to take the bolts out and turn the work.

JANUARY 19. The Prevention of Scale in Steam Boilers. The Principles of Modern Physics. A Criticism on Mr. J. B. Stallo's Concepts and Theories of Modern Physics. Crucible Cast Steel Rudder for S. S. La Plata.

The La Plata having nearly proven a loss by the breaking of her rudder during a storm in the North Sea, it was determined to try crucible cast steel. The rudder having been successfully cast was subjected to the following tests: The rudder was laid horizontally, with its ends resting on supports. The rudder blade was loaded with an evenly distributed weight equal to a total of 12,300 lbs., and balanced by a weight of 2240 lbs. at the end of a lever 12 feet long, securely fastened to the rudder-head 6½ ins. diam. The effect of the lever itself was 3920 lbs., weighing as it did 784 lbs., with an effective length of 5 feet. The rudder-head therefore sustained a torsional strain of $(2240 \times 12) + (784 \times 5) = 30{,}800$ foot pounds. While under this torsional strain a 2000 lb. weight was dropped from a height of four feet, striking at centre of the area of blade, and in neither case was there any sign of a twisting movement in the rudder-head. The rudder was then lifted to a height of 9 feet and dropped on the hard floor of the foundry without the slightest fracture. Being suspended again and tested with hand hammers, it rung like a bell from end to end.

Steam Boiler Furnace Economy.

An editorial on the subject of smoke prevention and furnace economy.

JANUARY 26. The Electrical Transmission of Power, by Prof. Oliver J. Lodge. The Movement of the Water in a Tidal River, by Prof. W. C. Unwin. The Foundering of Steamships.

Commenting on the sinking of the Cimbria and the frightful loss of life attending it, following so quickly as it does on the loss of the City of Brussels, attention is called to the utter thoughtlessness or carelessness with which owners of iron ships are allowed to send them to sea. Some figures are given showing the utterly insufficient strength given to bulkheads, which usually consist of plates ½ inch in thickness or less, stiffened by a few angle irons quite incapable of sustaining a hydrostatic pressure of 6 lbs. or 7 lbs. per sq. in. A double bottom in addition to high pumping capacity is earnestly demanded as a needed reform.

Regulator for Dynamo-Electric Machines.

A machine, patented by Mr. Maxim, for which the inventor claims the combination, with a dynamo-electric machine, of brushes arranged to revolve about the commutator, a system of gears for shifting the brushes, a reciprocating lever or pawl arranged to impart movement to the gears in either direction, and an electro magnet controlling the position of the reciprocating pawl.

FEBRUARY 9. Causes of Glacier Motion. Read before the Royal Society, by W. R. Browne. The Polyphemus.

This vessel is nothing but a ram, unless she is also an utter failure. She is fitted with special appliances for discharging torpedoes under water from her bows and her sides; and up to the present nothing but disappointment has attended every effort to use these last. The torpedoes fired from the bow ports have at all events been got away from the ship; but as much cannot be said of those discharged from her broadside.

The Polyphemus has attained a speed of 17 knots per hour, and the moment the torpedo shows its nose outside of the hull, it is deflected by the apparent current alongside the ship, and it is therefore jammed in the tube. If it can be got clear of this, it is only with its screw blades broken and its tail twisted that the luckless torpedo gets off; and it is not curious that the short curve which it then describes is erratic in the extreme. To prevent this a steel plate is pushed out from the ship's side, and under the lee of this the torpedo is discharged; but the resistance of the water has bent the steel bar, leaving the torpedo sticking half in and half out of the ship. Up to the present the targets aimed at, at distances of but 200 and 300 yards, appear to be specially avoided by the torpedoes, the ship steaming at 8 knots an hour or less. It is now also officially announced that the boilers are to be removed, but it is not announced how they are to be taken out, as the turtle-shaped deck is covered all over with Whitworth steel tiles, and to get those off and replace them without racking the whole structure, will be no easy matter.

The Electric Light on H. M. S. Himalaya. The Transmission of Power by Electricity.

An exhibition of the transmission of power by the system of M. Deprez. The trial did not prove as effective as was hoped, although M. Deprez claims that he has already demonstrated from an electrician's point of view, the correctness of his system.

FEBRUARY 16. Battle Ships, by Mr. Nathaniel Barnaby, C. B.; read before the United Service Institution.

Mr. Barnaby looks forward to ships of about 2000 tons displacement, carrying two heavy guns of about 25 or 30 tons each, one firing ahead and the other astern; the vitals of the ship are to be protected as far as possible by being placed below water, and by the use of horizontal armor decks. He expects that side armor will almost entirely disappear, being confined to a thick steel-faced or steel wall, protecting heavy guns; and that consequently the onslaught will consist chiefly in what has been termed the secondary attack made by common shells on unarmored parts of the ship.

ENGINEERING.

JANUARY 5, 1883. The "Bausan."

A new vessel in the course of construction at the Elswick works for the Italian Government. Length over all, 296 ft. and 42 ft. beam; displacement, 3020 tons. The ship will have twin screws driven by two pairs of compound engines of 5500 total horse-power, imparting a velocity of about 17 knots per hour. She will carry 600 tons of coal, 200 of which will be supplementary and are not allowed for in the displacement given above. With a full supply of coal on board she will be able to steam 5000 miles at a reduced speed of 10 knots. The armament will consist of two 25-ton breech-loading guns of the Elswick pattern on the ribbon coil system, firing a projectile of 3 cwt. with a charge of 182 lbs. of powder, and considered capable of penetrating 19½ inches of compound armor, and six 6-inch breech-loaders firing 60-lb. projectiles. The two large guns will be placed, one at the bow and the other at the stern, mounted on pivoted frames, and capable of being trained so as to embrace an angle of 240° each. The ship will have three sets of torpedo-discharging apparatus, one at each side and one at the bow, and will also be furnished with a powerful ram. The total cost including arms and ammunition is to be but £160,000.

JANUARY 12. Clyde Shipbuilding and Marine Engineering in 1882.

A summary of the work done on the Clyde during the past year.

The Use of Concrete in Marine Construction.

JANUARY 19. The Nordenfeldt Machine Guns. A complete description of all the Nordenfeldt Volley Guns. Timmis & Hodgson's Reversible Life Boat.

Received the first prize at the Naval Exhibition, and consists of two similar tubular hulls or chambers connected by a horizontal platform. Along the top and bottom of each chamber is a strip which serves either as a keel or gunwale, according to which half of the boat is above water. The hull is made of steel provided with water-tight bulkheads. The deck is open, and for a ship's boat is made of network, so that it can be launched without davits and in any position, it being a matter of indifference which side comes uppermost in the sea.

Sinclair's Self-acting Stoker.

A description of mechanical firing by Sinclair's method. The contrivance has been applied to upwards of 200 furnaces, effecting in most cases it is claimed an important saving in fuel and an increase in the production of steam, with, at the same time, almost complete cessation of the evolution of smoke.

Modern Ordnance.

An examination of the various breech-loading systems which approach the requirements of a perfect gun.

JANUARY 26. King's Governor for Water Motors. Manufacture of Pig Iron in Sweden. Electric Lighting. The Report of Mr. C. W. Cook on the Probable Cost of Lighting by Incandescence on a Large Scale.

FEBRUARY 2. Steel.

Papers read before the Institute of Mechanical Engineers on the amount of carbon in steel and the molecular rigidity of tempered steel, by Prof. D. E. Hughes, F. R. S.

Drilling, Boring and Shaping Machines. Siemens-Martin Furnaces at the Graz Steel Works. Girdwood's Isometric Governor.

Its action is based upon the use of an appliance that offers a resistance to rotation and increases with the velocity. The appliance used in this case is a hollow drum partly filled with fluid and rotating on a horizontal axis. When the cylinder is put in motion, the liquid is carried up one side to a height that is determined by the speed, and, if the motion be uniform, it will remain at that point, and will offer a resistance to rotation which increases in proportion to its lateral displacement ot its centre of gravity. Should the speed increase, the liquid will rise still higher and offer additional resistance. These varying resistances are balanced by a spring which responds to them by contracting and expanding, and in so doing gives the motion for operating the governing mechanism.

FEBRUARY 16. Non-Conducting Coverings for Boilers and Steam Pipes.

A lengthy and comprehensive series of experiments to determine the comparative efficiencies of the different non-conducting coverings that are now in the market.

An Automatic Primer for Pumps.

An exceedingly simple and ingenious method devised by Mr. Normand, for expelling the air which accumulates in the clearance space of pump barrels and in the valve chambers. To obviate the necessity of pet cocks, and to prevent the cessation of pumping, a small pipe about $\frac{2}{16}$ in. in internal diameter is introduced into the pump at the highest point at which the air can accumulate, while the other end opens into the tank from which the water is drawn. When the plunger descends, the air which may be in the barrel is compressed and escapes through the tube, bubbling up through the water. When the plunger ascends, the water passes through the tube and into the pump, and thus priming it without the attention of any one in charge.

JOURNAL OF THE FRANKLIN INSTITUTE.

JANUARY. The Chemistry of the Planté and Faure Accumulators. The Spectroscope and the Weather.

An exhibit by the Astronomer Royal of Scotland of some of the results obtained in predicting rain by the "rainband spectroscope." Some observations made are as follows:

Date.	Mean Temp.	Intensity Rainband.	Rainfall Observed.
Sept. 1, 1882.	57.1 F.	3	.044 inch.
2	59.2	2	.353
3	58.6	2	.015
4	54.4	0	
5	55.7	1	
6	55.2	0	
7	53.8	1	
8	59.4	0	
9	54.0	1	
10	57.0	1	
11	52.2	1	.40
12	48.6	0	
13	52.8	1	
14	49.5	3	.62
15	56.2	2	.57

The intensity of the rainband is of course estimated, and the accuracy with which this intensity can be estimated seems at present to limit the utility of the spectroscope as a meteorological instrument.

MARCH. Crank Pins of Marine Engines (J. H. Whitham, U. S. N.)

GIORNALE D'ARTIGLIERIA É GENIO.

NOVEMBER, 1882. Austrian siege gun of compressed bronze, model of 1880. The new trains made of nine centimetre plates. The Japanese breech-loading gun, model of 1880. The military telegraphic service in France.

JOURNAL OF THE MILITARY SERVICE INSTITUTION OF THE UNITED STATES.

No. XII. Field artillery in the United States before the civil war. Extracts from the history of Franco-German war. Mina and his three hundred. Notes on fundamental points in our military system.

INSTITUTION OF MECHANICAL ENGINEERS.

NOVEMBER, 1882. The Fromentin automatic boiler feeder. Experiments on flanging steel plates cold by hydraulic pressure. Experiments to ascertain the strength of cast iron beams for beam engines.

MITTHEILUNGEN A. D. GEBIETE D. SEEWESENS.

No. II. The type of the modern marine engine. Type of the modern battle ship. Organization, administration and material of the French navy. Russian marine ordnance. 100-ton gun of the Italian navy. Caspersen's pendulum chronograph. Ader's microphone sender. Notes on the French and Russian navies. The French and American expeditions for the observation of the transit of Venus.

REVISTA GENERAL DE MARINA.

DECEMBER, 1882. Notes on Service in the Philippines. On Naval Combats between 1860 and 1880. Tallerie Hydraulic Motor. The Dandolo. Lights of Safety.

A scheme of Capitan de Fragata Mansanos for avoiding collisions at sea involves the addition of two extra side lights which he calls "lights of safety." The ordinary running lights would be carried as usual, but placed well aft, while the safety lights would be placed on the forecastle or in the fore-rigging. Parallel screens are placed on either side of these lights at an angle of 45° with the keel, of such a length as to prevent their being seen except in an arc from nearly ahead to 10° forward of the beam. The lights would be of the same color as the running lights, red and green respectively. The plan is designed for steamers only, the presence of the masthead light avoiding all risk of the lights being taken for those of two vessels standing in the same direction. The safety lights being visible only broad off the bow would indicate within a few points the course steered by the vessel carrying them, while a change of course would be made evident by the appearance or eclipse of these lights, the ordinary side lights and masthead light continuing to show as before.

JANUARY, 1883. Notes on Naval Service in the Philippines. Tallerie's Hydraulic Motor (in use aboard the Aragon for working the helm). Naval Organization. Dimensions of Fundamental and Derived Units. Notes on the London Electrical Exhibition. Determination of Position at Sea by Circles of Equal Altitude. Notes on Combined Military and Naval Operations.

FEBRUARY. Notes on Naval Service in the Philippines. Fundamental and Derived Units. The London Electrical Exhibition. The Aneroid Barometer. Notes on Combined Military and Naval Operations.

Automatic Electric Lighting Apparatus for Beacons.

An automatic apparatus used on a beacon in the harbor of Cadiz. By means of a clock-work regulator and an electro-magnet, a light is produced for ten seconds at a time, with twenty second eclipses throughout the night, the light being caused by the inflammation of benzine vapor by the sparks of a Ruhmkorff coil. During the eclipses and during the day there is no loss of benzine, and the batteries are cut out of circuit by an insulator in the clock-work. It is said to have worked without the slightest interruption since May 16, 1881, requiring occasional attention only.

RIVISTA MARITTIMA.

NOVEMBER, 1882. Reflections on naval tactics. The naval appropriations. On the formation of cyclones. Naval warfare, the military ports of France (trans.) Thornycroft torpedo boats (trans.) Experiments at Meppen (trans.) Collisions at sea.

DECEMBER. Notes on naval tactics. The Italian naval appropriations. The mercantile marine and the auxiliary fleet in war. The naval review of 1882. The cruising torpedo ram. The physiology of cyclones.

JANUARY, 1883. Notes on naval tactics. Coast defense. The national marine strength. The Italian naval appropriations. Progress in the navy. On ironclads and the modern naval combat. Experiments with plates at Spezzia. The proportion of officers in the navy.

THE UNITED SERVICE.

MARCH, 1883. Relative Rank of the Officers of the Austrian, German, Italian, French, English and United States Navies, arranged on the basis of the Army Rank.

This article, translated from the "Mittheilungen a. d. Gebiete des Seewesens," by Prof. C. E. Munroe, is valuable for reference, giving, as it does, not only the exact relative rank of officers of foreign navies with those of our own, a point not always easy to determine, but also showing the relative rank of officers of different corps in each of the leading navies of Europe.

MÉMOIRES DE LA SOCIÉTÉ DES INGENIEURS CIVILS.

OCTOBER, 1882. Report on the International Congress of Hygiene and of the meeting of the French Association for the Advancement of Science. Description of the port of La Rochelle. The coal of Asia Minor. Utiliza-

tion of the subterranean heat. The coal production of Sweden. Distillation of sea water at Alexandria during the Egyptian War. Valves of phosphor-bronze. The attractive force of steel rendered permanent by compression. Bourdon's registering anemometers.

NOVEMBER, 1882. The coal industry in Austria. Shipbuilding on the Clyde.

Memoir on Thermodynamics.

This memoir embodies a new theory of gases, in which the laws of Gay Lussac and Mariotte, which fail for certain gases like carbon dioxide, and the hypothesis of a perfect gas, are abandoned. The theory is tested by comparison of the calculated data with the results of experiments, and it is applied to the interpretation of isothermal and adiabatic curves.

BOOKS RECEIVED.

Almanach für die K. K. Kriegsmarine. 1883.
American Geographical Society. No. 2, 1882.
American Society Civil Engineers. Oct., Nov., 1882.
American Institute of Mining Engineers. Nineteen Papers.
American Philosophical Society. Transactions, Nos. 110, 111, 112.
Conziderazioni sulla Tattica Navale.
Giornale d'Artiglieria é Genio. Nov., Dec., 1882, Unofficial; and Nos. 7, 11, 12, 13, 15, 16, 17—1882, Official.
Institute of Mechanical Engineers (England). Transactions, No. 4, 1882.
Journal de la Flotte. No. 53, 1882, to No. 9, 1883, inclusive.
Journal of the Franklin Institute. Feb., Mar., 1883.
Journal of the Military Service Institution of the United States. No. 12.
Journal of the Royal United Service Institution. No. 118.
Nautische Tafeln der K. K. Kriegsmarine.
Réunion des Officiers, Bulletin. No. 51, 1882, to No. 4, 1883, inclusive.
Report of Ch. Eng. Isherwood on Vidette Boats built by the Herreshoff Manufacturing Co. for the British Government.
Rivista Marittima. Jan., Feb., 1883.
Royal Artillery Institution. Proceedings, Vol. XII, with Précis and Translations.
School of Mines Quarterly. No. 2. Vol. IV.
Société des Ingénieurs Civils. Mémoires, Oct., Nov., 1882.
United Service. Mar., 1883.
U. S. A. Ordnance Notes. Nos. 233, 234, 235.

AMERICAN PHILOSOPHICAL SOCIETY,

PHILADELPHIA, PA.

EXTRACT FROM THE BY-LAWS.

CHAPTER XII.

Of the Magellanic Fund.

SECTION 1. John Hyacinth de Magellan, in London, having in the year 1786 offered to the Society, as a donation, the sum of two hundred guineas, to be by them vested in a secure and permanent fund, to the end that the interest arising therefrom should be annually disposed of in premiums, to be adjudged by them to the author of the best discovery, or most useful invention, relating to Navigation, Astronomy, or Natural Philosophy (mere natural history only excepted); and the Society having accepted of the above donation, they hereby publish the conditions prescribed by the donor and agreed to by the Society, upon which the said annual premiums will be awarded.

Conditions of the Magellanic Premium.

1. The candidate shall send his discovery, invention or improvement, addressed to the President, or one of the Vice-Presidents of the Society, free of postage or other charges, and shall distinguish his performance by some motto, device or other signature, at his pleasure. Together with his discovery, invention or improvement, he shall also send a sealed letter containing the same motto, device or signature, and subscribed with the real name and place of residence of the author.

2. Persons of any nation, sect or denomination whatever shall be admitted as candidates for this premium.

3. No discovery, invention or improvement shall be entitled to this premium which hath been already published or for which the author hath been publicly rewarded elsewhere.

4. The candidate shall communicate his discovery, invention or improvement either in English, French, German or Latin language.

5. All such communications shall be publicly read or exhibited to the Society at some stated meeting, not less than one month previous to the day of adjudication, and shall at all times be open to the inspection of such members as shall desire it. But no member shall carry home with him any communication, description or model, except the officer to whom it shall be intrusted; nor

shall such officer part with the same out of his custody without a special order of the Society for that purpose.

6. The Society, having previously referred the several communications from candidates for the premium then pending to the consideration of the twelve counselors and other officers of the Society, and having received their report thereon, shall, at one of their stated meetings in the month of December, annually, after the expiration (of this current year of the time and place, together with the particular occasion of which meeting, due notice shall be previously given by public advertisement), proceed to final adjudication of the said premium; and, after due consideration had, a vote shall first be taken on this question, viz. Whether any of the communications then under inspection be worthy of the proposed premium? If this question be determined in the negative, the whole business shall be deferred till another year; but, if in the affirmative, the Society shall proceed to determine by ballot, given by the members at large, the discovery, invention or improvement most useful and worthy; and that discovery, invention or improvement which shall be found to have a majority of concurring votes in its favor shall be successful; and then, and not till then, the sealed letter accompanying the crowned performance shall be opened, and the name of the author announced as the person entitled to the said premium.

7. No member of the Society who is a candidate for the premium then depending, or who hath not previously declared to the Society that he has considered and weighed, according to the best of his judgment, the comparative merits of the several claims then under consideration, shall sit in judgment, or give his vote in awarding the said premium.

8. A full account of the crowned subject shall be published by the Society, as soon as may be after the adjudication, either in a separate publication, or in the next succeeding volume of their Transactions, or in both.

9. The successful performances shall remain under consideration, and their authors be considered as candidates for the premium for five years next succeeding the time of their presentment; except such performances as their authors may, in the meantime, think fit to withdraw. And the Society shall annually publish an abstract of the titles, objects, or subject-matter of the communications, so under consideration; such only excepted as the Society shall think not worthy of public notice.

10. The letters containing the names of authors whose performances shall be rejected, or which shall be found unsuccessful after a trial of five years, shall be burnt before the Society, without breaking the seals.

11. In case there should be a failure, in any year, of any communication worthy of the proposed premium, there will then be two premiums to be awarded the next year. But no accumulation of premiums shall entitle the author to more than one premium for any one discovery, invention or improvement.

12. The premium shall consist of an oval plate of solid standard gold of the value of ten guineas. On one side thereof shall be neatly engraved a short Latin motto suited to the occasion, together with the words: "The Premium of John Hyacinth de Magellan, of London, established in the year 1786"; and on

the other side of the plate shall be engraved these words: "Awarded by the A. P. S. for the discovery of —— A. D. ——." And the seal of the Society shall be annexed to the medal by a ribbon passing through a small hole at the lower edge thereof.

SECTION 2. The Magellanic fund of two hundred guineas shall be considered as ten hundred and fifty dollars, and shall be invested separately from other funds belonging to or under the care of the Society, and a separate and distinct account of it shall be kept by the treasurer.

The said fund shall be credited with the sum of one hundred dollars, to represent the two premiums for which the Society is now liable.

The treasurer shall credit the said fund with interest received on the investment thereof, and, if any surplus of said interest shall remain after providing for the premiums which may then be demandable, said surplus shall be used by the Society for making publication of the terms of the said premiums, and for the addition, to the said premium, of such amount as the Society may from time to time think suitable, or for the institution of other premiums.

The treasurer shall at the first stated meeting of the Society in the month of December annually, make a report of the said fund and of the investment thereof.

BOSTON, *March* 14, 1883.

LIEUT. J. B. MURDOCK, U. S. N.,

Corresponding Secretary, &c., Annapolis, Md.

DEAR SIR:—The undersigned, in performance of the duty assigned to them by the Executive Committee of the United States Naval Institute, as judges to determine to whom should be awarded the prize and gold medal offered by that Association for the best essay submitted in its competition for the year 1883, upon the following subject, "How may the sphere of usefulness of naval officers be extended in time of peace with advantage to the country and the naval service," unanimously recommend that the award be made to the author of the essay with the motto "Pour encourager les autres." The judges also consider worthy of honorable mention the two essays under the following mottoes respectively: "Semper paratus" and "Cuilibet in arte suâ credendum est." It is proper to state that all the judges do not adopt in full the recommendations and arguments of these essays in recognizing the ability and felicity of their presentation.

Very respectfully yours,

ALEXANDER H. RICE,

J. G. ABBOTT,

GEO. HENRY PREBLE.